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DESCRIPTION OF "ENVIRONMENTAL STANDARDS FOR CARBON MONOXIDE" AND GUIDELINES FOR THEIR ACHIEVEMENT

M. FUJIWARA

1. Problem of Air Pollution by Carbon Monoxide

Carbon monoxide is a colorless, tasteless, odorless and non-irritating gas; unlike sulfur dioxide, its inhalation does not produce any subjective symptoms such as irritation of throat. But accidental inhalation of high concentration of carbon monoxide may cause fatal casualties in extreme cases. Fortunately, the concentration of this gas in the atmosphere of cities is not so high as to cause such casualties, but it is necessary to take precautions against the persistent and chronic condition of pollution by this gas. Unlike other pollutants, carbon monoxide is not significantly decreased by the natural reactions occurring in atmosphere and almost 2-3 years are required for some decrease through adsorption by rain and earth and oxidation to CO_2. Hence, according to geochemical studies, the concentration of carbon monoxide in atmosphere seems to be increasing. As mentioned earlier, the concentration of the gas in the atmosphere of the cities is rapidly increasing. The question is, what are the sources of this CO gas? The sources which immediately come to mind are automobiles, factory chimneys, domestic heaters, jet planes, etc. Calculation of the quantity of CO generated as a result of consumption of fuels of the petroleum group shows that in the whole of Japan there is an annual emission of 5,860,000 t of CO from automobiles, 8100 t from factories, and 5,500 t from jet planes. In Tokyo alone, about 950,000 t, 1,100 t and 1,500 t of CO are emitted from automobiles, factories and jet planes respectively. The major part of CO released in the city thus comes from automobiles, and CO pollution in the cities is mainly due to the gas emitted from automobiles. In some few cases, CO pollution in towns is also due to leakages in the gas supply system.

There are about 14,000,000 automobiles at present in Japan and the number is increasing every year. The number of automobiles in California (the area of which is more or less the same as that of Japan), where gas emission from automobiles have come to be looked upon as the biggest problem, is about 10,000,000. The annual total production of automobiles in Japan was about 41,000,000 in 1968. It is far higher than the production in West Germany where the number is 31,000,000 and even greater than in America where it is 11,000,000. Again, the increase in production in Japan every year is considerably higher on an average 25-30%, whereas there is hardly any increase in the rate of annual production in America, West Germany, France, England, Italy, etc. Analysis and study of the number of automobiles with respect to living area in major countries showed that Japan ranks first in automobile density and it is far above America. (Fig. 1).

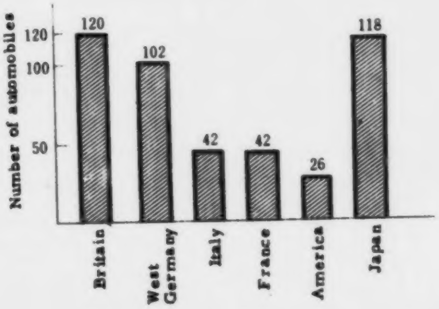


Fig. 1. International comparison of the number of automobiles per km² area.

Note:1. The area taken for the study does not include the regions of forest, dairy farms and fields;

2. Number of automobiles as in 1968.

The data for America, Britain, West Germany, Japan, and Italy were obtained from the Automobile Associations of the respective countries. The data for France were obtained from The Motor Industry of Great Britain. The data for the areas are according to the United Nations statistics.

2. Establishment of Environmental Standard

The environmental standard for carbon monoxide was decided after much discussion on February 20, 1969. The decision was included in the environmental standard of air pollution under Clause No. 2.

ENVIRONMENTAL STANDARDS FOR CARBON MONOXIDE

It is needless to mention that carbon monoxide is one of the three major air pollutants found in the cities of Japan, the other two being sulfur oxides and particulates. In the past, it was feared that there might be individual exposure to air pollution arising out of the use of domestic appliances such as room heaters, etc. or because of pollution caused by emissions from chimneys or because the profession of the individual is of a special type such as that of a mine worker. But now the amount of carbon monoxide found in the air and inhaled with the air by the general public is something that cannot be ignored. Carbon monoxide forming within a house can be checked to some extent by the inmates of the house themselves. The problem in relation to the special types of profession is not of direct concern to the common public. But in the case of the atmosphere covering the cities, if the pollution continues unabated day and night, day after day, one has to inhale the air whether it is pure or impure even though the impurity may not be of high concentration; and if the pollution continues year after year a stage will be reached when it becomes dangerous to public health, in particular to deceased persons, old people and children. The question now is what exactly should be the safe level of concentration? The problem is not as simple as it appears to be. The standard of concentration of air pollution that can be safe for the public (this is what is known as environmental standard) is difficult to define as it involves problems not only of social and administrative character but also of physiological nature. Thus, although it is briefly described as a health problem, it is difficult to define explicitly as the range is very wide from a stage where it should not cause illness to a stage where there should be no influence on the general psychological and mental conditions. Thus, the problem is whether the physical health alone should be taken as the main basis.

The same type of discussions were held on this point at the time of the establishment of environmental standards of sulfur oxides and there also the starting point of the discussions was the same as in the case of carbon monoxide. WHO has also suggested consideration of health problems at four levels. However, these are only guidelines for consideration. Each country has its own laws, restrictions and methods of administration that may differ from those of other countries and therefore any decision on environmental standard should be made in accordance with its own laws, restrictions and administrative set up (environmental standards in foreign countries will be discussed later). One of the problems that has not been much studied is in regard to the exposure to low concentrations of carbon monoxide gas for a long period and the effect of such exposure on health. This is not a problem confined only to Japan but there has not been sufficient study on this matter even in other countries. The importance of such studies has now been recognized and various countries are persuing this aspect, viz. the influence of prolonged exposure to low concentration of carbon monoxide. Studies so far carried out have shown that there is influence from low concentration of the pollutant if the exposure continues for a long period, namely, one or two years. As it is proposed to study the influence by epidemiological methods on particular groups of people, the results cannot be obtained rapidly and easily. Besides, there are various other difficulties encountered during the course of the study.

The course for the establishment of environmental standards for carbon monoxide is as follows: When the environmental standard for sulfur oxide was formulated on February 12, 1969, after much discussion, it was found that in the meantime air pollution caused by gas emitted from automobiles had increased to a point where the establishment of environmental standard for carbon monoxide had come to be anxiously looked forward to. The Ministry of Health took the same steps as in the case of sulfur oxides, that is, a discussion was started as from June 31, 1969 by an expert committee invited to the Conference. The Expert Committee consisted of Dr. T. Suzuki, Director of National Public Health and Hygiene Institute, as the Chairman and ten other experts variously in the fields of medicine, engineering, chemistry, pharmacology, etc. The report of the Expert Committee, after a total of fourteen meetings, was placed before the meeting on environmental protection held on September 11 the same year. A discussion, on the basis of this report was held at the meeting. This was followed by further discussions on December 22 the same year and a meeting with the Minister of Health. A guideline was prepared by the Ministry of Health on the basis of this report and after consultations between the various concerned Ministries, an environmental standard was formulated on February 20, 1970.

3. Outlines of Environmental Standard

Environmental standard prescribes a pollution level that will not affect the health and life standards of common people and is a valued protective measure against public hazards to be implemented through the administration. According to this standard, the pollution should be below the prescribed level and if the pollution exceeds this level even slightly, public health will be adversely affected. If the excess conditions persist, it might result in increase in mortality rate, particularly among old or sick people. This increase in mortality rate can be avoidded by keeping the pollution within the standard prescribed and thus maintaining a favorable condition of the environment. If and when the pollution exceeds the prescribed standard level the administrative wing of the government should implement the various countermeasures and bring down the pollution. The course of action is different from those applicable in respect of the emission standard covering the various emission sources and a direct control is not applied. However, in order to maintain the environmental standard, the regulations should be made more stringent and it is believed that the question of formulating an indirect regulation of the emission source should also be taken into consideration. The environmental standard is clearly defined in Clause No. 9 of the Basic Law of Environmental Protection brought into force in August, 1967. According to this law, protection of human health is foremost in importance and towards this end a level of pollution which will not have an adverse influence on human beings from the physiological point of view is prescribed. On the basis of safe environment, the level has been adjusted to economic development. This is how Japan has established the environmental standard and it would be interesting to find out the course followed by other countries to establish the environmental standard of their respective countries. The course is different in different countries and in order to deepen knowledge of environmental standards in Japan a few representative examples are described below:

In Los Angeles, the standard involves three types of pollution, viz. CO, CO_2, and oxidants. If the level exceeds the prescribed standard, the administration intervenes accordingly to the extent of the contravention of the prescribed standard.

In other words, a standard of excess level for CO is established in three stages, viz. 100 ppm, 200 ppm and 300 ppm. If the level exceeds only the first of these stages, a restriction is imposed on the movement of automobiles; if it moves up to the second stage, an overall check on the automobiles is made and in case the third stage is reached, the Disaster Relief Law is invoked. Under similar circumstances in Japan, emergency regulations under Pollution Prevention Law are invoked.

In West Germany, there is a standard known as M-K (Maximale Imission Konzentration) established by the Technical Cooperative Association (VDI). This seems to be more or less the same as the environmental standard of Japan. When a workshop is to be erected in a particular area where there is already some pollution, since the emission from the new workshop would add to the pollutant, the quantity of emissions from the new workshop should be such that the maximum concentration of the pollutant in the area is maintained at a level below M-K. This is a standard permitted under the industrial law of that country and at the same time it is also based on a judgment of the receiving capacity of the public.

In U.S.S.R., the permissible concentration is taken into consideration for the formulation of the environmental standard and the standard is made in such a manner that it neither adversely affects human beings nor reduces productivity. Since the standard is completely based on the hygienic aspect of environment, the concentration prescribed is extremely low. For the time being standards have been established in respect of 96 substances. Regardless of whether the standard of U.S.S.R. is truly applicable in Japan keeping in view the prevailing conditions here, it is hoped that the standard may be accepted as an ideal to be achieved.

As has already been mentioned, the environmental standard in Japan is defined under the Basic Law of Environmental Protection. A standard was formulated for administration by the government and in order to achieve and maintain the standard, the policy to make the emission standards more stringent and plans to check public hazards are being worked out. Therefore, this standard does not yet operate as a restriction on permissibility with regard to pollution and is not even a rule to be enforced if the standard is not maintained. It is only an objective for the administration in its formulation of countermeasures against public hazards.

4. Report of the Meeting of the Expert Committee

In the deliberations of the Expert Committee on the environmental standard for carbon monoxide (the Committee convened under the Public Hazards Section of the Environmental Protection meeting under the auspices of the Minister of Health) persons of various fields of endeavour participated and a purely academic standard of environment was discussed. One of the subjects considered at the meeting held for discussion of safe environment was "Environmental Standard of Carbon Monoxide". The report of the meeting on this subject was received with some concern by the Minister of Health. The Expert Committee of the meeting on this subject was received with some concern by the Minister of Health. The Expert Committee of the meeting consisted of ten members from various fields such as medicine, engineering, chemistry, pharmacology, etc. The first meeting was attended by, besides the members of the Expert Committee, several invited scholars and technologists and at this meeting an academic study was carried out. The Expert Committee consisted of the following members:

Chairman	T. Suzuki	Director of National Public Health and Hygiene Institute
Member	T. Umezawa	Chief of the Health Division
Member	T. Ohira	Chief of the Air Division, Tokyo Public Hazard Research Institute
Member	T. Kita	Chief of the Communication Division, Shipping & Technology Institute
Member	A. Koizumi	Asst. Professor, Tokyo School of Medicine

Member	Y. Kobayashi	Asst. Professor, Faculty of ~~Engin~~ Engineering, Yokohama National University
Member	M. Tomura	Chief of Chemistry Division, National Hygiene Research Center
Member	T. Toyama	Professor, University of Medicine
Member	N. Yamaki	Chief of Industrial Technical Research Center, Public Hazards Division
Member	H. Watanabe	Director of Hygiene Research Center, Hamakura Prefecture.

(arranged in the order of Japanese syllabary).

A total of seven meetings of the Expert Committee were held in 1970, the first meeting being on January 31st. A meeting with Mr. Yamaki as Chairman was held to consider the question of measurement of carbon monoxide, whereas the meeting with Mr. Watanabe as Chairman was held to consider the question of the adverse influence of carbon monoxide on human beings. A report of these meetings was published on September, 11.

The following outlines the contents of the report published by the Expert Committee:

Permissible CO concentration:

As a result of discussions by the Expert Committee it was found that the permissible concentration came within the following two limits:

(1) The mean value for one hour in a continuous period of eight hours should be below 20 ppm.

(2) The mean value for one hour in a continuous period of 24 hours should be below 10 ppm.

The mean value for one hour in a continuous period of eight hours is calculated by taking eight readings of the concentration of CO during this period at intervals of one hour. Thus, the meaning differs from what is usually meant by mean value for eight hours in the sense that in this case eight separate readings are taken during this period. Similarly, the mean value for one hour in a continuous period of 24 hours means the mean value calculated from 24 separate readings of the concentration at intervals of one hour during this period.

These two limits were suggested after studying the various effects of carbon monoxide on human beings both in Japan and in foreign countries. The suggestion was followed by an explanation of the numerical value of the standard (concentration of CO).

Carbon monoxide is considered to affect the health of human beings in the following three ways:

(1) CO combines with hemoglobin of the blood and its combining capacity becomes about 240 times stronger than that of the oxygen. Thus, the functioning of the carbon monoxide hemoglobin in the transport of oxygen is considerably obstructed.

(2) The physiological function of the body is also affected as the CO either reacts directly or combines with oxygen present in the body.

(3) Carbon monoxide hemoglobin (COHb), although in small quantities, is naturally produced in the body. When there is no CO in the atmosphere, it is smoothly exhaled out, but if there is CO in the atmosphere, the separation of CO from the lungs becomes disturbed.

In other words, CO firstly causes oxygen deficiency; secondly, it acts as a poison and damages the organs; and thirdly, CO hinders normal breathing condition. Of these three effects, the effect of CO causing oxygen deficiency has been widely investigated and its presence has been confirmed. However, regarding effects (2) and (3), the investigations are yet in the initial stage.

In the report of the Expert Committee the effect of CO as under item (1) is treated as the basic issue. The report also stresses its concern regarding low concentration of CO and severe effect of prolonged exposure particularly under the conditions explained in (2) and (3). The reports of the studies carried out in Japan as well as in foreign countries have also been considered.

The salient points made in the various reports are:

(1) In order to avoid hindrance to the release of CO produced naturally within the body, from the lungs and also to maintain a complete and smooth physiological functioning of the body the concentration of CO in the inhaled air should be below 5 ppm.

(2) In order to exhale CO absorbed from various sources of CO pollution like smoke, room heaters, kitchen, atmosphere, etc. the concentration of CO in the environment should be low. For example, in order to reduce the increased COHb content* in an individual who had been breathing air for 8 hours with mean concentration of CO for one hour as 20 ppm, it is necessary to reduce the mean one hour-value to below ppm and this condition should continue at least for 8 hours. If the mean value for one hour is converted to mean value for 24 hours it works out to 10 ppm.

(3) The reduction of CO can be called effective if the reduction rate per hour reaches a stage where COHb is 2%. For example, when CO polluted air is inhaled for 24 hours, the mean one hour value of CO concentration taken for 24 hours should be below 10 ppm so that COHb content can be maintained at 2% or below. On the other hand, the one-hour value of CO concentration should be below 55 ppm when CO polluted air is inhaled for one hour. (In this case, the CO concentration before and after the exposure to polluted air was assumed to be below 5 ppm).

(4) Heart patients (thrombosis) are easily affected by CO-pollution when mean value for 24 hours calculated from one-hour values continues to be at 10 ppm for a few days.

COHb content is the ratio of COHb to total Hb.

(5) When the COHb content reaches 5%, the function of the nervous system is impaired and this may be fatal for anemic patients and those suffering from circulatory disorders in the essential organs of the body. The COHb content increased to 5% when CO concentration continues to be 30 ppm for 8 hours.

On the basis of the abovementioned facts, the safe level of concentration of CO (10 ppm for 24 hours and 20 ppm for 8 hours) was fixed. The following is an account of the important context in which the question of CO-concentration was considered.

(1) The effect of CO is considered independently as distinct from the effect of concentration of CO in a mixed action with other substances where the so-called pollution index is used. This is different from the case where sulfur oxide is considered as air pollution index. In the case of sulfur oxide, the influence is often found to be a co-related action of various sulfur oxides (SO_2, SO_3 etc.) and particulates. In the measuring method (electric conductivity method) it is sulfur oxide which covers the major part and sometimes substances other than sulfur oxide are also estimated by conductivity method.

In air pollution, these substances (i.e., substances other than sulfur oxides) cannot be ignored and all those which are measured by the electric conductivity rate method are collectively called sulfur oxides. Hence, the air pollution in this case is expressed as air pollution index of sulfur oxides and not as an individual influence of sulfur oxides. On the other hand, the influence of carbon monoxide taken for the present study can be considered separately and the measurement can also be carried out by separating the carbon monoxide on the basis of non-diffusion type infrared analysis. The standards for CO pertain to the influence of CO alone and are not taken as the index. However, it is not that in the case of CO the idea of air pollution index cannot be entertained. For example, in the State of California the concentration index in respect of air pollution caused by automobile exhaust gas is fixed. In Japan, there is no such index.

(2) The exact nature of the influence of prolonged exposure to low concentration of CO (exposure ranging from a few months to about one year) on man is still not fully determined. The

present standard is on the basis of the influence due to short period exposure. Unlike the case of sulfur oxides, the standard is not established from the results of epidemiological investigations on groups of people exposed for long periods.

(3) Although it is said that CO should be below 5 ppm, owing to the following reasons this is not taken as the standard value. Normally COHb content should be below 2% but even then there are physiological reactions. For complete removal of natural CO from the lungs, it is said that CO should be below 5 ppm. This is the reason why 5 ppm is taken as the most representative standard. This condition should exist particularly during sleep at night.

Method, place and duration of measurement:

i) Place of measurement:

Air pollution caused by CO from automobile exhaust gas is severe in about one meter of the sidewalk pavement of roads with heavy traffic but it rapidly decreases beyond this or away from the traffic concentration. However, the present view is that depending upon weather conditions, the CO-pollution is said to spread widely from the traffic congested roads. In the present way of measuring pollution, the stress is on the measurement of localized pollutions. However, it is necessary to have a measuring network both for localized pollution and regional pollution.

ii) Method of measurement:

The standard way of measuring CO concentration is by using non-diffusion type infrared analysis (NDIR) and it is better to measure for a continuous period. However, it can also be measured by other methods which will yield the same results as those of NDIR method. Gas chromatography is one of such methods yielding similar results.

The NDIR consists of an analyzer which absorbs the infrared rays of CO molecules and in Japan, it is often known as infrared gas analyzer. The response is rapid and it is possible to choose the measuring range between 0~50 ppm. The precision of measurement is ±2% of full-scale. The important components which disturb the measurement are carbon dioxide and water and since the influence of these components might result in yielding an inflated value, it is necessary to minimize their influence.

The instrument used in the past was much inferior as the deviation was ±25%. However, since the instrument could be used easily, it can be applied to check regional pollution.

As measuring method of CO concentration, besides those mentioned above, there are the mercury oxide method, the gas chromatography method, the iodine pentoxide method, etc. but these have not yet been adopted.

iii) Duration of measurement:

Regarding the duration of measurement, duration of sample collection should be in accordance with the influence. But at the meeting of the Expert Committee one hour was recommended as unit time since most of the recent reports have indicated this unit to be convenient. Thus, when a continuous measurement is carried out on the basis of NDIR method, the results of measurement with 1 hour as the unit time are arranged. Again, when the samples are collected in plastic bags, it is necessary to make the sampling with 1 hour as the unit time.

5. Environmental Standards Prescribed by the Cabinet

Following the publication of the report of the Expert Committee, the issues were taken up and discussed at various levels such as investigations by a sub-committee of the Safe Environmental Conservation Association (with Prof. Kanazawa of Tokyo University as the Chairman), understanding with Environment Protection Department, discussion with Health Minister, drafting of the Bill by Health Ministry, negotiations with other ministries like Transportation, Trade and Commerce, Home (police), Construction etc., drafting of proposed ammendments, reporting to the Central Environment Protection Association (with Prof. Wadatsu of Saitama University as the Chairman), consent by vice-ministers, passing of the Bill by Environment Protection Committee and finally by the Cabinet (February 20, 1970).

The environmental standards finally decided by the cabinet were published in a report on February 23. The contents of the report are as follows:

The numerical value of environmental standards are the same as those reported by the Expert Committee. Besides, the report also mentions the measures necessary for attaining the standards.

Environmental standards for carbon monoxide:

(1) Numerical value of environmental standards:

Considering the influence of carbon monoxide, the environmental standard of carbon monoxide safe for man, should satisfy the following conditions throughout the year:

(i) The mean one-hour value during a continuous period of 8 hours should be below 20 ppm.

(ii) The mean one-hour value during a continuous period of 24 hours should be below 10 ppm.

(The actual significance of these two conditions is already mentioned in the report of Expert Committee).

The environmental standards for carbon monoxide suggested by various countries are shown in Table 1. The standards in Japan are more or less similar to those in California and New York. However, they are very much different from the standards of USSR as the subject of environmental standards is treated in different ways in the two countries.

(2) Limits of Application of Environmental Standards:

The environmental standards should be applicable to any region or place to ensure normal living and activities of public. However, the standards are not applicable to places where there is very heavy traffic flow or places utilized for temporary stay ([illegible]).

(3) Method of Measurement:

TABLE 1

Environmental standard of carbon monoxide in various countries

Place	Concentration	Remarks
USSR	1 mg/m^3 24 hours; 6 mg/m^3, short duration	24 hour mean value: 0.35% COHb (carbon monoxide hemoglobin)
America (Panel of 1967 Electric Powered Vehicles)	10 ppm	8 hours
America Pennsylvania	25 ppm	24 hour mean value, any where at any time
America, California	20 ppm, 8 hours	2% increase in COHb in 24 hours among persons who did not inhale smoke; hindrance to central nervous system. Possibilities of automobile accidents. Increase in the mortality rate of heart patients.
America, New York (Class C-3 Ward)	15 ppm	8 hour mean value, the value should not increase above 15% in a year.
	30 ppm	8 hour mean value, the value should not increase at any time.
	60 ppm	One hour mean value, the value should not increase more than 1% in a year.

By using NDIR (non-diffusion type infrared analyzer) the measurement is carried out continuously and the results are calculated at intervals of one hour.

Regarding the places for measurement, only those places are selected where the results of measurement can be effectively applied for studying the pollution trend, influence on man and benefit of control measures.

(4) Measures for attaining the environmental standards:

In view of the assumption that most of carbon monoxide is given out by automobiles, it is necessary to implement the following measures against automobile exhaust gases.

(i) Tightening of exhaust regulations:

Considering the increasing rate of pollution due to automobile exhaust gas, increasing number of automobiles, fuel consumption and the traffic, graded but strong measures should be determined and then implemented in order to maintain carbon monoxide in the automobile exhaust gas at a permissible level.

(ii) Strengthening of the system of checking:

Along with a complete implementation of a checking device related to carbon monoxide of exhaust gas from the automobiles for the sake of persons driving the automobiles, it is also equally important to improve the machinery and tools as well as the technique in the implementation of this checking device in the automobile equipment factories.

(iii) Dissemination of knowledge of driving operations (omitted)

(iv) Study of communication regulation system:

In order to effectively carry out the countermeasures against pollution due to carbon monoxide in the automobile exhaust gases particularly when public health is threatened, proper maintenances of communication regulations related to the roads are ensured by checking.

(v) Improvement in measuring equipments used for inspection:

In order to control air pollution due to carbon monoxide in automobile exhaust gas, the measuring equipments for inspection should be improved. Particularly in the important cities, it is necessary not only to improve the equipment of inspecting network but also to have a telemeter network for communication regulation system.

Regarding the measuring system of air pollution by carbon monoxide, roads and traffic should be classified according to specific conditions.

(vi) Progress of research study and technical development (omitted).

(vii) Establishment of countermeasures for automobile exhaust gas in urban regions.

In urban areas, besides establishing the countermeasures for carbon monoxide in automobile exhaust gas, plans for developing a similar device for communication and transportation system should also be taken up. Specially, the road surroundings should be much improved so that traffic is smooth.

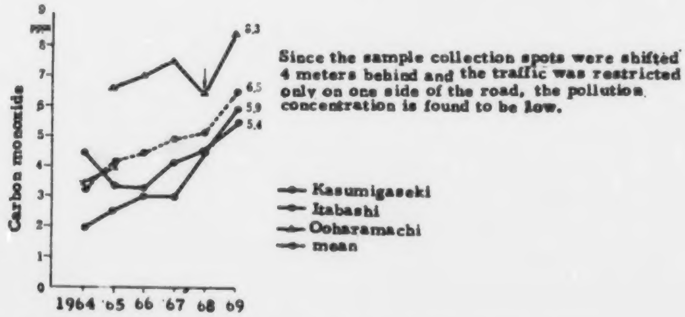
6. Comparison with Pollution in the Existing State of Affairs

When the present state of pollution caused by carbon monoxide is studied in the light of the environmental standard described earlier, the following facts are observed. According to the data collected at various places in Tokyo, namely Ocharamachi, Kasumigaseki, Itabashi, National Hygiene Research Center (measurement carried out by Health Ministry), in front of Metropolitan Office, Kōjiya Insurance Office, Jōtō Insurance Office (measurement carried out by Tokyo Metropolitan Government), the number of the days in terms of percentage on which the level exceeded the environmental standards (of the two conditions the percentage of days was high when the level exceeded 10 ppm for 24 hour period and hence on this basis the percentage of the number of days in which the level exceeded the environmental standard is expressed) was (in 1969) 25.8% in Ocharamachi, 1.9% in Kasumigaseki, 1.2% in Itabashi, 0.9% in National Hygiene Research Center, 53.5% in front of Metropolitan Office, 1.8% in Kōjiya Insurance Office and 0% in Jōtō Insurance Office. The percentage increases with the increase in the annual mean concentration of carbon monoxide. Table 2 shows the percentage of the number of days on which the level exceeded the environmental standard and the annual mean value in 1969 measured at different places. From this Table, it is clear that in order to maintain the environmental standard, the annual mean value should be below 4 ppm.

TABLE 2

Place of measurement	Ooharamachi	Kasumigaseki	Itabashi	National Hygiene Research Centre	In front of Metropolitan Office	Kōjiya Insurance Office	Jōtō Insurance Office
Annual mean value (ppm)	8.3	5.4	5.9	4.5	10.6	4.8	2.6
Percentage of days on which the pollution exceeded environmental standard (%)	25.8	1.9	1.2	6.9	53.5	1.8	0

The variations in the annual mean values of carbon monoxide concentration in Ooharamachi, Kasumigaseki and Itabashi, are shown in Fig. 2. The figure shows that there is a steady increase every year and it should be brought down considerably to satisfy the environmental standard. For instance, it should be brought down to half its present concentration in Ooharamachi.



Since the sample collection spots were shifted 4 meters behind and the traffic was restricted only on one side of the road, the pollution concentration is found to be low.

Fig. 2. Changes in the annual values of carbon monoxide (1964-1969).

The frequency distribution of 1-hour value, mean value for a day, maximum 1-hour value in a day, maximum 8-hour value in a day and 8-hour value obtained from the results of measuring the pollution at Ooharamachi and Kasumigaseki, are plotted in probability verification paper and logarithmic probability verification paper and the results are shown in Figures 3 and 4. The ordinate shows the value of concentration of CO and the abscissa shows the probability of excess concentration.

7. Monitoring of Pollution

Measurement of CO-pollution is necessary to see whether the environmental standard is being maintained or not.

However, except in unusual weather conditions, pollution by CO is not as widespread as pollution due to sulfur oxides, and hence the measured values differ according to the places chosen and this again gives rise to several other problems.

Since monitoring is a device to check how far human beings living in a particular place are exposed to the pollution, the place where the concentration is maximum and inhabited by human

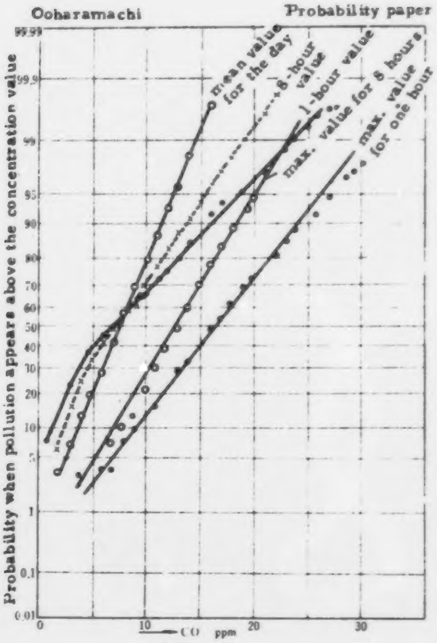


Fig. 3.

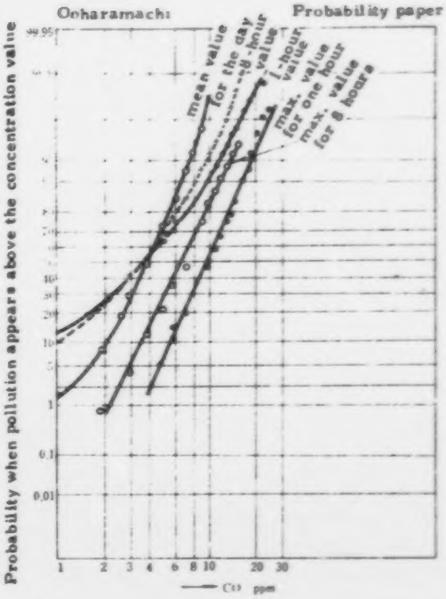


Fig. 4.

beings should be taken first for measuring. However, this should not be done without first finding out which place is most polluted. Again, even if such a place is found, it will not adequately give a correct picture of the extent and distribution of pollution of the whole urban area. It would be better to supplement the survey with additional monitoring at several fixed points in the following manner:

(i) First of all, the pollution covering a wide area should be measured on a broad scale by a simple method.

(ii) Secondly, the region in which the pollution concentration is found to be maximum according to the results of (i), should be subjected to a more accurate measuring method. In order to measure the pollution of a wider area, the samples should be collected and an estimation carried out according to NDIR.

(iii) The regions where the pollution is believed to be severe as judged from the results of (i) and (ii) are taken as the representative checking points and treated as the fixed measuring place. On the other hand, the possibility of shifting the Observation Station to these spots should also be considered. An automatic device for measurement according to NDIR method should be set up at these spots.

In Japan, the measurement of air pollution due to automobile exhaust gas, as compared to the measurement of air pollution caused by smoke emitted from the factories seems to be considerably behind both in the number of measuring stations and the quantity of measured data. Hence it is necessary to study this problem by introducing the abovementioned monitoring system. Regarding the fixed measuring places of (iii), as shown in Table 3, there are altogether 12 such places in Tokyo Metropolitan and Osaka City. One of these is located in the Office of Health Ministry. (i) and (ii) are being carried out on short term basis at several places in the country by Public Sector groups.

At present, the measurement of CO in Japan is carried out at 12 stations, namely, 7 in Tokyo Metropolitan, 3 in Osaka City, one at Nagoya City and one at Chiba Prefecture. Of these, 5 are National and 4 are managed by Metropolitan Council and Prefectural Administration. Three are under the City Administration. The Station started in 1964 is the oldest. The National Observation Stations installed at Kasumigaseki and Itabashi were started in 1964 and are now about five-and-a-half years old. The location of the Station at Ooharamachi is at the crossing point of Kōshū Kaidō and Circular line No. 7. The automobile traffic for one day in this area is about 110,000 120,000 vehicles. The Observation Station at Kasumigaseki is just within the campus of the Health Ministry Office. This faces Iwaidabashi Dori, and vehicular traffic per day is 35,000~45,000. The Itabashi Station is located in the campus of the Itabashi Scavengery Office. It faces Nakasendō (National Road No. 17). The vehicular traffic per day is 40,000~45,000. The sample collection in these three places is carried out at a height of 2 meters between the road and footpath. The four Stations of Nagoya and Osaka are also located around the main roads. On the other hand, the National Hygiene Research Center, Kōjiya Insurance Office and the Chiba Prefectural Environment Protection Research Center have the Stations 100~450 meters away from the main roads. In these places, it is the regional pollution which is measured and recorded rather than the direct measurement of exhaust gases on the roads.

TABLE 3

Position and measuring items in Observation Stations during normal conditions

		Sample collecting regions	Relation between sample collecting locations, position and main streets		Measuring items (excepting CO)	
Name of cities and regions	Measuring points	Names of Streets and roads	Distances from the traffic road (m)	Height from the surface of road (m)	Names of pollutants*	Weather data
	Ooharamachi	Kōshū Kaido Circular Line No. 7	0	2	NO, NO_2, Dust SO_2 (Excess of HCHO in Kasumigaseki)	Nil
	Kasumigaseki	Iwaidabashi Dōri	0	2		
	Itabashi	Nakasendo	0	2		
Tokyo Metropolitan	National Hygiene Research Center	Kodaki Dōri	450	6	NO, NO_2, SO_2 HC, O_3	Wind direction, wind velocity, temperature and humidity
	In front of Metropolitan Office	Street in front of Metropolitan Office	3	2	NO, NO_2, SO_2 HC, Dust	Nil
	Kōjiya Insurance Office	Sangyo Doro	150	12		
	Jōtō Insurance Office	Shin Ohashi	70	6		

Chiba Prefecture	Environment Protection Association	National Road No. 16	100	10	SO_2, NO_2	Wind direction, wind velocity, temperature and humidity
Aichi Prefecture	Sakae Kōsaten	Hirokoji Dōri	0	2.5	Nil	Nil
Osaka City	Morinomiya	Honcho Fukae Sen	50	3~5	SO_2, NO, NO_2, HC, O_3	
	National Hygiene Research Center	Tenjinbashi Dori	50	15	SO_2, NO, NO_2, O_3 HC, Dust	Wind direction, wind velocity, temperature and humidity
	Kinugasachō	Midosuji Dori	4	2	NO, NO_2, SO_2 Dust	Nil

*Note NO	:	nitrogen monoxide;
HC	:	Hydrocarbon
Pb	:	Lead
NO_2	:	Nitrogen dioxide
O_3	:	Ozone
HCHO	:	Formaldehyde
SO_2	:	Sulfur dioxide
Cl_2	:	Chlorine

8. Approach for Attainment and Maintenance of Environmental Standards

When the results of monitoring the pollution explained earlier show that the pollution is below the environmental standard, efforts should be made to see that the pollution does not increase more than this level. But in case the pollution is already above the environmental standard, it is necessary to take official steps so that the pollution can be brought down. In order to do this, it is necessary to implement all the necessary steps as prescribed and directed by government starting with checking the automobile exhaust gases. The measures which are deemed to be directly effective in bringing down the pollution concentration are as follows:

(i) Tightening up of the regulations for control of CO in automobile exhaust gas.

(ii) Thinning out traffic concentration by remodifying the roads.

(iii) Control of traffic concentration at the time of high pollution.

Regarding the stringent measures to control the CO emission, it was already stressed in September 1969 that the CO concentration in the exhaust gas of new automobiles should be below 2.5%. At present, when the regulations are yet to be implemented on the automobiles which are not so old, the CO-concentration during idling time should be below 5.5% (since August this year). Again, regarding light vehicles, and LPG vehicles the present regulations are not applied but these are expected to be included under the regulations in the near future.

Regarding the restriction on traffic, modification of Road Traffic Law should be made and when the air pollution due to carbon monoxide of the automobile exhaust gas is severe, there should be effective restriction on the traffic concentration, a study of which is being carried out under the auspices of the Home Ministry. The important topics which are to be studied in future are the relationship between the exhaust standard and environmental standard as in the case of enforcing the exhaust standard for sulfur oxide and the formation of ideal exhaust standards for attaining and maintaining the environmental standards.

Regarding the tightening of the regulations of CO, since it is feared that the concentration of nitrogenous oxides would increase along with a decrease in CO of the exhaust gases, the improvement should not be based on CO alone but on all the components of the automobile exhaust gas.

PHOTOCHEMICAL REACTIONS OF AUTO EXHAUST

S. YANAGIHARA

1. Introduction

Even before the Second World War, it seems people knew that the nature of air pollution in Los Angeles was different from that in London, only in the post-war period it was found that the pollution was due to photochemical reactions.

This air pollution can be called photochemical smog causing formation of oxidants, irritation in the eyes, degeneration of plants and decrease in visibility. The components of this type of air pollutants include hydrocarbons and nitrogen oxides given out by automobiles and other sources. These react to solar radiation and form ozone (O_3), nitrogen dioxide (NO_2), aldehydes (R. CHO), alkyl nitrate ($R.ONO_2$), peroxyacetyl nitrate or peroxyacyl nitrate ($R.CO_3NO_2$) etc. All these are called oxidants and are easily oxidized.

In recent times, in Japan also, measurement of oxidant is being carried out and concern about the so-called photochemical smog is also rising. Automobile, exhaust gas is considered to be not only a source of CO-pollution but also a factor causing photochemical smog. Apart from the presence or absence of photochemical smog, it is very important to understand the special features related to photochemical reaction of automobile exhaust gases in Tokyo as in the case of pollution in Los Angeles.

Insofar as automobiles particularly the gasoline vehicles are concerned, it is not all that difficult technically speaking to control CO exhaust. However, the control of oxides of nitrogen ($NO + NO_2$ or NO_x) and hydrocarbons (Cn. Hm or HC) which are believed to be closely related to the formation of photochemical smog is not always easy. Specially in the control of NO_x, there are a number of technical difficulties. For example, it is very difficult to sufficiently reduce NO_x exhaust in the case of internal combustion or external combustion engines. Again, regarding HC, the reactivity is considered to be a very important factor and the angle of study would change according to its role in the formation of smog. As oxidants, besides O_3 and R.CHO, a number of chemical compounds of hydrocarbons having NO_2 or N or O are found to be present. Among these, the factors causing eye-irritation and degeneration of plants are believed to be different. However, as regards decrease in visibility, the influence of sulfur oxides (SO_2) and moisture is considered to be very high.

As far as weather and visibility conditions are concerned the effect of automobile exhaust gas might be insignificant. However, if the main cause factor of smog is assumed to be in the automobile exhaust, it is very important to study the photochemical reaction of exhaust gases and develop a technique to make it harmless.

Although rather belatedly, the author carried out an experimental study of the photochemical reactions, the results obtained are presented here. For the sake of reference, the results obtained by several investigators in America are also included and an attempt has been made to explain the photochemical reaction in air pollutants.

2. Absorption of Solar Light

As in the case of photographic film, the so-called photochemical reactions occur in solid- as well as in liquid phases. In the case of gaseous phase, it will be recalled that the break up of alkyl lead which is the antiknock agent in the fuel used in the automobiles, is due to photochemical reaction.

It will not be a mistake to assume that the photochemical reaction begins only when a certain reacting substance is activated by light energy. In this case, the substance absorbs photon and if the rate of absorption is α_λ and if the incident light I_0 becomes I after passing through the layer when the concentration is C and the thickness of layer is d, the following equation is obtained.

$$I = I_0 e^{-\alpha_\lambda C d} \quad \cdots\cdots\cdots\cdots (1)$$

α_λ differs according to the substance and the wave length and the absorption rates of the substances mainly present in atmosphere are shown in Table 1(1). This table clearly shows that the absorption rate of NO_2 is relatively high and its wave length-range is also very wide. The absorption of solar light by NO_2 is shown in Fig. 1. However, NO_2 becomes NO_2' by absorbing h_ν and it is said that the energy involved in freeing of NO and O is 71-72 Kcal/mole. This is equal to the energy at 4000 Å. Hence, the irradiation and absorption at a wave-length range below 4000 Å cause problems.

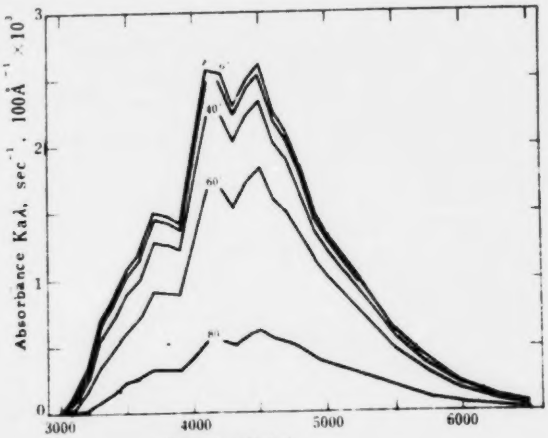


Fig. 1. Absorption wave length of NO_2.1)

Components other than NO_2 may also be excited by absorbing photon but O_2 or SO_2 is not a source of energy to cause dissociation.

On the other hand, the solar light is distributed from 2200 Å to more than 10,000 Å (vide Fig. 2). The main problem is in the ultraviolet range. In fact, the light energy in the lower layers of atmosphere is mostly reduced after passing through the air layer. This can be expressed by the following equation.

$$I_{t\lambda} \quad I_{o\lambda}\cdot e^{-\alpha\lambda m} \tag{2}$$

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TABLE 1

Substances in atmosphere absorbing solar light
Range: 3000-7000 Å. Zenith angle, Z = 0°

Substances	Wave length range Å	Absorption rate $K\alpha\ hr^{-1}$
Oxygen (O_2)	7590-7660	9.0×10^{-7}
	6870-6920	
Ozone (O_3)	2500-3500	(0.58)
	(2900-3500)	
	4500-7000	1.16
Nitrogen dioxide (NO_2)	2900-7000	
	2900-3850	26
	3850-4150	22
Sulfurous acid gas (SO_2)	2900-3500	0.94
Nitric acid (HNO_3)	2900-3300	1.8×10^{-2}
Alkyl nitrate ($C_2H_5ONO_2$)	2900-3300	$1. \times 10^{-2}$
Ethyl nitrate (C_2H_5ONO)	2900-4100	7.1
Nitroethane ($C_2H_5NO_3$)	2900-3500	0.22
Acetone	2900-3300	0.08
Acetaldehyde	2900-3400	0.3
Methylpropenyl ketone	2900-3800	1.8
Acrolene	2900-4000	2.2
B. acetyl	2900-4700	6.1
Acyl nitrite		
Nitrate		
Fine grains		

Here, $I_{0\lambda}$ and $I_{t\lambda}$ represent the density of light in wave-length range before and after passing through the atmospheric layer. m indicates the quantity of air and σ_λ represents the attenuation coefficient. m changes according to the angle of sun (Zenith angle). σ_λ is influenced by the dispersal of the molecules or fine grains, absorption by ozone and cloud. σ_λ greatly changes if there is cloud or mist, but while studying the photochemical reactions on a clear day this factor (σ_λ) need not be taken into account.

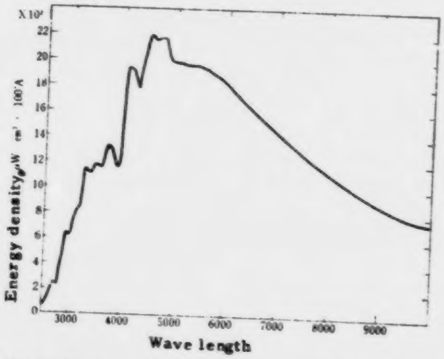

Fig. 2. Energy distribution of mean solar rays (outside the covering of atmosphere).

There is reflection near the earth surfaces and sky radiation and when the wave-length is more than 3500 Å, the energy distribution is believed to be more than 1/3 of the value as shown in Fig. 2.

Since in the experiments carried out in the laboratory, fluorescent lamp is used for ultraviolet irradiation, the energy distribution in this case differs from that of solar light. Moreover, when the light passes through a window, the absorption should also be taken into consideration. The distribution of photoenergy of fluorescent lamp with energy peak at 3500 Å as compared to the same of solar light is shown in Fig. 3[2]. The author carried experiments with light density of 700-1000 μW/cm^2 at 3450-3550 Å. In the case of experiments carried out in America, a light density of 1200 μW/m^2 seems to have been used(2).

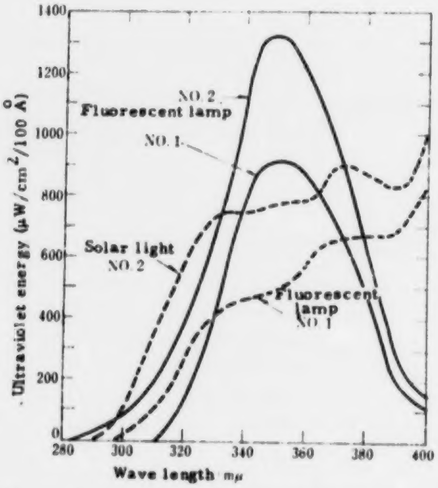

Fig. 3. Distribution of irradiation energy.

The photochemical reactions of automobile exhaust discussed below deal mainly with the role played by the decomposition reaction of NO_2. However, the course of experiments carried out indicated that the problem was related to the conversion of NO from NO_2.

3. Course of Reaction

All the reactions occurring in atmosphere are not completely known. According to Caplan[3)] the following chain of reactions seem to occur:

$$NO + O_2 \rightarrow NO_2 \quad (3)$$

$$NO_2 + h\nu \rightarrow NO_2' \quad (4)$$

$$NO_2' \rightarrow NO + O \quad (5)$$

$$O + O_2 \rightarrow O_3 \quad (6)$$

$$O_3 + HC \longrightarrow RCHO + RCO_3' \quad (7)$$

$$O_3 + NO \rightarrow NO_2 + O_2 \quad (8)$$

$$O + NO_2 \rightarrow NO + O_2 \quad (9)$$

$$O + HC \rightarrow R' + RCHO \quad (10)$$

$$R' + O_2 \longrightarrow RO_2' \quad (11)$$

$$RO_2' + NO \longrightarrow RO' + NO_2 \quad (12)$$

$$RO' \rightarrow R' + O \quad (13)$$

$$RO' + NO_2 \rightarrow RONO_2 \quad (14)$$

$$RCO_3' + NO \rightarrow NO_2 + RCO_2' \quad (15)$$

$$RCO + NO_2 + O_2 \rightarrow RCO_3NO_2 \quad (16)$$

In fact, when there is no light irradiation, and the concentration of NO is about 1 ppm, the conversion of NO to NO_2 is very much delayed. The other reactions may also be delayed.

The reverse reaction of (6) occurs due to the influence of light. That is,

$$O_3 + h\nu \rightarrow O_3^{*} \rightarrow O_2 + O \qquad (17)$$

In the same way the reverse reaction of (14) and the breaking up of RCHO can also be assumed. Besides, light irradiation may influence either directly or indirectly several reactions other than (4).

In the laboratory experiments, if there is no light irradiation there is hardly any change in NO (below 1 ppm) and HC. NO_2 increases due to light irradiation and the oxidants also increase slightly. But when the whole amount of NO has been converted, the first signs of decrease in NO_2 and HC are seen. Oxidants continue to increase even after NO_2 had decreased considerably.

From these facts, it is clear that the early stages of HC and NO control the speed of reaction but it is not clear whether the progress in the reaction is affected by any other factors. On the whole, the increase in oxidant and changes in NO_2 weaken the reaction, but it is not possible to determine the course of reaction in detail with the help of these factors only.

4. Irradiation Experiments

4.1. Experimental apparatus:

The apparatus in which the photochemical reactions can be caused by applying ultraviolet rays equivalent to solar light to sample gas is known as the smog chamber. In this case, the apparatus used is an irradiation chamber and if the volume is small, the sample cell of infrared photometer itself is also used. When the volume is large, it has a capacity of more than 10 m^3 and if the equipment has additional parts it may even be larger with plant exposing chamber.

Fig. 4 shows structure of the smog chamber used by the author. The automobile exhaust gas is diluted to a few thousand times with clean air and then passed into the smog chamber.

Here, ultraviolet rays are applied and the photochemical reactions are made to reappear. The apparatus has chassis - dynamometer or engine-dynamometer for generating the exhaust gas by controlling the driving conditions similar to the running conditions of an automobile or its engine on roads, shunt for exhaust gas, air regulator for dilution, 2-stage dilutor, radiation chamber, light source and sample gas analyzer.

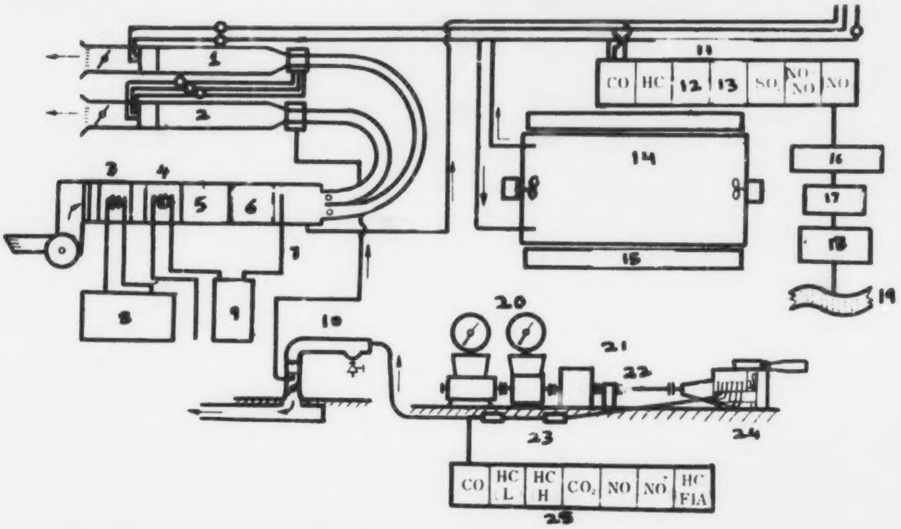

Fig. 4. Structure of smog chamber.

1 - 2-stage dilution, 2 - 1-stage dilution; 3 - condenser; 4 - heater; 5 - filter; 6 - active carbon filter; 7 - Humidizer; 8 - Freezer; 9 - Bioler; 10 - 1/5 shunt; 11 - Analyzer; 12 - Aerosol ; 13 - Oxidant; 14 - Radiation chamber; 15 - Light source; 16 - Signal; 17 - AD convertor; 18 - Punching machine; 19 - Tape; 20 - Dynamo; 21 - Flywheel; 22 - Torque meter; 23 - Air exhauster; 24 - Engine; 25 - Analyzer.

The radiation chamber in this apparatus has a capacity of about 11 m^3 and had windows covered with tefflon sheet. The chamber was made of aluminum. Although in America, the windows are covered with quartz glass, the author found that even tefflon had good permeability for ultraviolet rays and the surface reactivity was also not inferior. The light was derived from 300 fluorescent lamps of 100 W each. They had the energy peak at 3500 Å. Standard density of light was taken as 1000 $\mu W/cm^2$ (3450-3550 Å).

The gas analyzer was used for analyzing CO, HC, NO + NO_2, NO_2, SO_2, oxidant and aerosol. Colorimetric method was applied to CO (50 ppm of NDIR), HC (10-100 ppmc at FID). Continuous colorimetric method of Saltzman reagent was applied to NO + NO_2 and NO_2 (2 ppm with 0.3 ppm as central value). Oxidant was analyzed by colorimetric method with free KI at 365 mμ and SO_2 by electrical conductivity method. In all these the fullscale was 2 ppm.

Among these, the measurement of oxidant had several problems. In this case, I_2 is detected in the reaction

$$O_3 + 2\,KI + H_2O \rightarrow I_2 + 2\,KOH + O_2 \cdots\cdots\cdots (18)$$

and there are several problems involved in the correcting methods also.

4.2. Photochemical Reaction of Hydrocarbon and Oxides of Nitrogen

Different hydrocarbons are found in the automobile exhaust and their reactivities differ from one another. Hydrocarbons of olefin group are of particular interest because of this relatively high activity. The following is a brief introduction of a part of the experimental data obtained mainly for ethylene (C_2H_4) found in considerable amount in exhaust gas.

Fig. 5 shows the variation in the concentration of various components when the experiments were carried out at an early stage with 2 ppmc of ethylene and 0.5 ppm of NO. In this case the concentration of HC could not be measured accurately even by FID method. The concentration is determined from the amount of HC entered into the radiation chamber but the changes could not be measured.

As is clear from the figure, the increase in NO_2 begins soon after irradiation. In this case, NO_2 increased to 50 pphm in about 3 hours after which it started decreasing. Oxidant also increased to about 10 pphm, but along with decrease in NO_2, it increased at a relatively rapid rate. After about 4 hours of irradiation, NO almost disappeared and NO_2 also decreased con

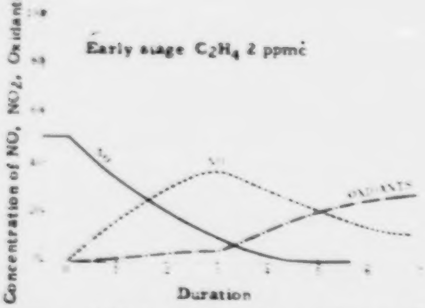

Fig. 5. Course of photochemical reaction of C_2H_4-NO.

siderably in 6-8 hours. However, oxidant continued to increase although slowly and reached 25 pphm.

Since, in this case, the effect of decrease in concentration due to air exchange in the radiation chamber was not corrected, it is believed that the concentration after 8 hours would have been about 50% more if the adjustment was made. The air exchange brings down the concentration to 7-8%/hr.

Under more or less the same conditions, when the concentration of HC and NO were changed, and a comparison of the pattern of the reaction course was studied, it became as in Fig. 6.

According to this figure, when the initial concentration of NO was small, both NO_2 and oxidant increased at a rapid rate. In the present experimental range, it was found that the reaction was more and more rapid as the ratio of HC/NO increased. However, if the duration of reaction was prolonged, or in other words a comparison of the values of oxidant beyond 8 hours showed that the ratio of HC/NO did show much change and the influence of HC concentration seemed to be stronger.

A three dimensional picture of the above-mentioned results, that is, HC and NO on the horizontal axis and NO_2 or oxidants on the vertical axis, is shown in Fig. 7. When the duration of the reaction was comparatively short, say 2-4 hours, a cubic surface with a ridge-like peak for oxidant could be visualized under the conditions of HC/NO more than 10. Regarding NO_2, the influence of original NO was stronger.

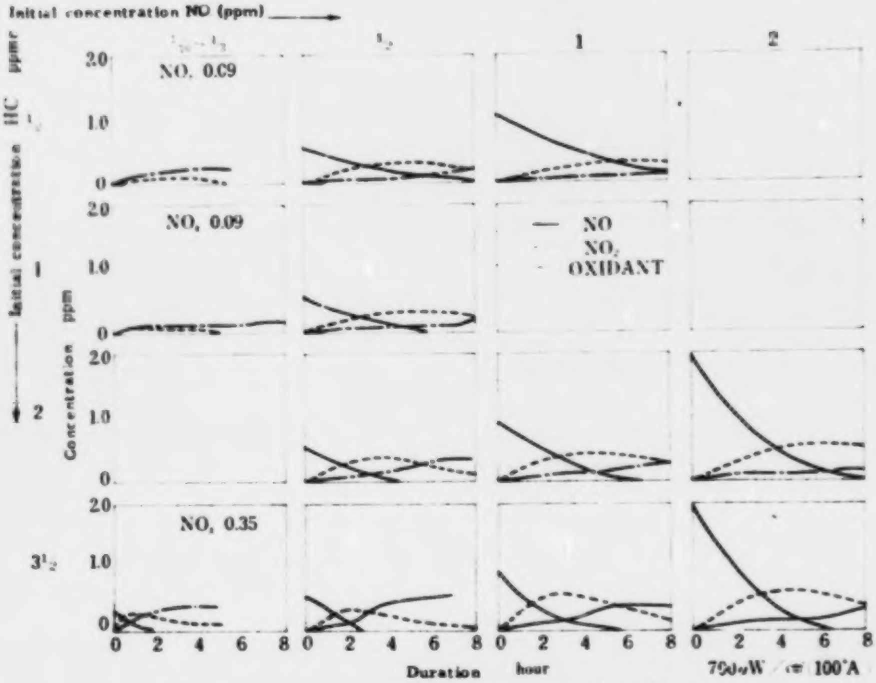

Fig. 6. Photochemical reaction of C_2H_4-CO.

Same type of reaction pattern is found in automobile exhaust gas and other hydrocarbons.

4. 3 Photochemical Reaction of Automobile Exhaust Gas

While carrying out experiments on automobile exhaust gases it is better to have a supply of sample gas having the composition of exhaust gas and the capacity to reappear when the conditions of the engine are constant. In the present experiment the exhaust gas samples were not only collected under idling condition and running at constant speed but also under other conditions like alternate increase-decrease speed or, the speed of the so-called california 7 mood,

Fig. 8 shows the exhaust gas during idling operation and the experiments were carried out by changing the density of light. In this case, since NO is small, the absolute value of NO_2 is

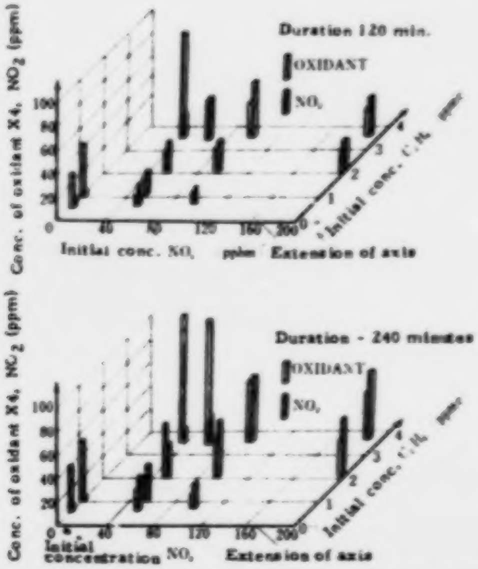

Fig. 7. Relationship between initial concentration of HC, NO_x and oxidant, $NO_2(C_2H_4\text{-}NO)$.

very small. However, the concentration of oxidants is considerably high. From early stage of reaction concentration of oxidant varies according to density of light. Along with increase in the energy of light, the value of oxidant also increases.

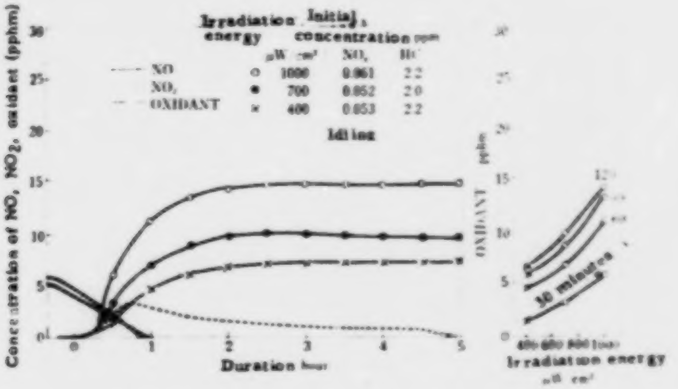

Fig. 8. Effect of irradiation energy.

Fig. 9 shows the condition when the concentration of NO was changed during idling and the air-fuel ratio was changed. Even at same concentration of HC, the value of oxidant increased along with increase in NO. In this case, the ratio of HC/NO was more than 50 and the influence of NO was also somewhat striking.

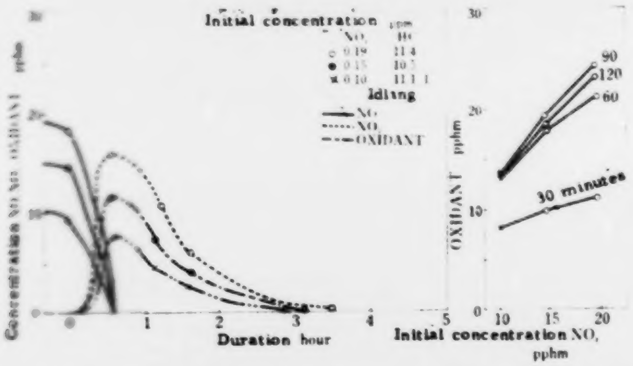

Fig. 9. Effect of change in NO-concentration during idling.

In other operating conditions, the ratio of HC/NO is usually below 10 and the reaction speed is slow. Fig. 10 shows a 3-dimensional view of the results of radiation experiment of exhaust gas under various operating conditions. The trend here is similar to that in Fig. 7. In fact, the composition of HC of exhaust gas changes according to operating conditions. Hence, it is not possible to determine the effect on the basis of concentration alone. However, Fig. 10 seems to indicate a general pattern on the basis of HC concentration.

Fig. 11 shows a comparative study of propane (C_3H_6), ethylene, exhaust gas and LPG (about 1/6 Vol. % of olefin is included in propane) when the concentration of HC is the same. In this case, the reaction speed decreases in the order of propane, ethylene, exhaust gas and LPG. A number of investigations on various types of HC are under progress to study the reaction speed.

Reactivity of hydrocarbon:

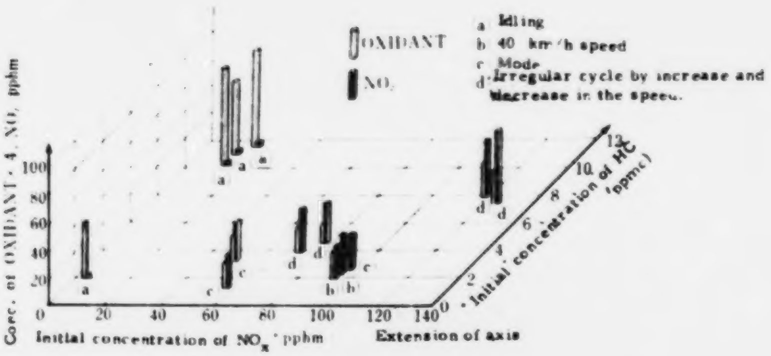

Fig. 10.Relationship between initial concentration of HC, NO_x and the concentration of oxidant, NO_2 (duration of irradiation - 120 minutes).

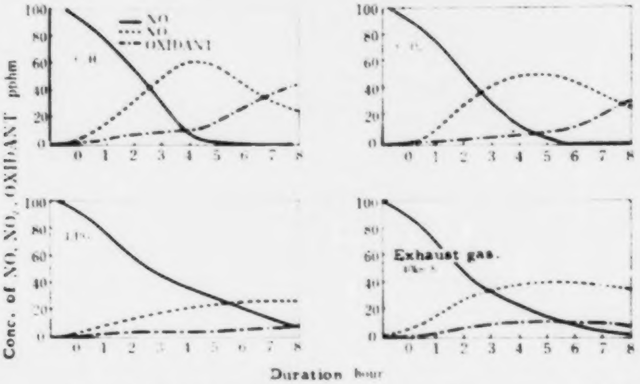

Fig. 11.Effect of hydrocarbons on photochemical reaction.

Reactivity of hydrocarbon has been studied by several investigators and the data reported by them are not the same. Altshuller[4]) has reported reciprocal values as shown in Table 2 and Fig. 12. It seems the reactivity of hydrocarbon can be discussed on the basis of the values reported by Altshuller. Usually, the low-grade paraffin almost lacks any reactivity but high-grade paraffin, olefin, alkyl-benzene and diolefin with more than C_6 seems to give rise to problems.

Heuss et al.[5]) have determined the reciprocal reactivity of various types of hydrocarbons and among these, the correlation of hydrocarbons and eye irritation is very poor as compared to other reactions.

TABLE 2

Comparison of reactivity of various organic compounds[4]

Reactivity of 0-10 scale

Substances	Ozone or oxidant	Peroxy, acyl nitrate	Formaldehyde	Aerosol	Irritant	Plant destroyer	Mean reactivity
C_1-C_5 Paraffin	0	0	0	0	0	0	0
Acetylene	0	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0
Paraffin with more than C_6	0-4	0	0	0	0	0	1
Toluene monoalkyl benzene	4	-	2	2	4	0-3	3
Ethylene	6	0	6	1-2	5	-	4
1-alkane	6-10	4-6	7-10	4-8	4-8	6-8	7
Diolefin	6-8	0-2	8-10	10	10	0	6
2 and 3 alkyl benzene	6-10	5-10	2-4	6-10	4-8	5-10	6
Double bonded alkane	5-10	8-10	4-6	-	4-8	10	8
Aliphatic aldehyde	5-10	-	-	-	-	-	-

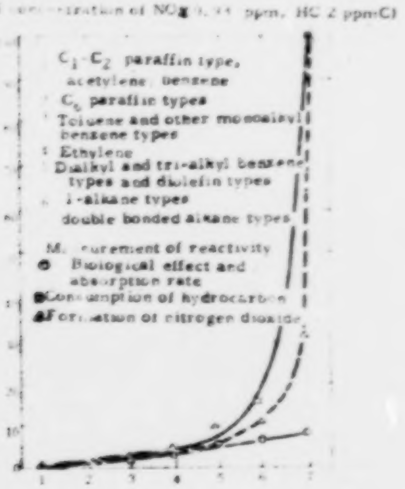

Fig. 12. Relationship between the type of hydrocarbon and the reactivity response obtained by different methods[(4)].

As index of eye-irritation, if t is taken to cause eye-irritation, the following equation is obtained.

$$\text{Eye-irritation index} = \frac{(240-t) \times 10}{240} \qquad (19)$$

By using the abovementioned equation, the sensitivity to various types of hydrocarbons was determined. The reactivity of aromatic olefin has also been studied. The structure of eye irritant is reported to be peroxybenzoyl nitrate (PBzN) which is identified as a component having slightly different wave length of infrared absorption than that of PAN. In the past, PAN attracted much attention as causing much damage to plants. However, if PBzN is assumed to be causing eye irritation, aromatic olefin becomes an important factor for consideration.

It is not absolutely proper to evaluate the factors in photochemical reaction by merely considering the hydrocarbons in automobile exhaust gas. Hence, several investigators are analyzing the various hydrocarbons by gas chromatography or estimating hydrocarbons after scrubbing off paraffin, acetylene, benzene etc. or by measuring the so-called active hydrocarbons. Although, these are indeed some of the methods of analysis, the technique involved does not seem to give a complete picture.

While studying the pollution in atmosphere not only the photochemical reaction of individual hydrocarbon, but also the influence of mixture of various types of hydrocarbons as well as the influence of other conditions should also be taken into account. In fact, it seems even those components which have poor reactivity should not be allowed to be released in large amount. However, this aspect requires further studies.

6. Conclusion

Today, the photochemical reactions of automobile exhaust have also become a serious problem in Japan. Regarding control measures of air pollution caused by automobile exhaust, Japan has introduced exhaust regulations for CO as a first step. In future, exhaust regulations for NO and the problem of photochemical smog might also have to be considered. Although today it is not a serious problem requiring immediate attention, it has all the symptoms of becoming a serious danger in future.

7. Literature

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EXHAUST EMISSION CONTROLS OF U.S.A. AND EUROPE

T. KOHAYAKAWA

1. Introduction

Air pollution is not a new subject. Even Romans in those days seemed to know about this phenomenon and it is believed that air pollution started on the day when human beings discovered fire. Air pollutants of natural world are also not less in number. Metals become corroded due to salt vapor from the seas, and the sand-dust causing air pollution can be compared to the occurrence of hoshigusabyo*, a disease caused by flower dust which is a natural air pollutant.

However, human life in recent times can be said to be tied up with air pollution. Starting from the first smoking of a cigarete after getting up from the bed, all substances which involve combustion for example the burning of any matter used for cooking or hot water used for washing of face etc. are related to air pollution and even in the case of electricity the thermal-power generation due to the combustion of the fuels is an important source of air pollution. Again there are several factors which on the whole look harmless and totally unrelated to air pollution, but a study of these substances reveals that these are always related to air pollution.

Thus, it is clear that wherever human beings live there is always air pollution and this degree of air pollution increases with the increase in population. The Meuse Valley incident of Belgium in 1930, the Donora incident of the state of Pennsylvania in 1948, the London incidents of 1952 and 1962 which caused a great loss of lives were all related to air pollution. These incidents should never be repeated again. Moreover, today the problem is not how to develop the industries in the country but how to protect the environment in which human beings could live safely.

**It is a name of disease and the English equivalent could not be found -- Translator.*

Under such conditions, the automobile exhaust gas is also considered to be a serious problem contributing to air pollution and this requires an early solution in the light of the above-mentioned information.

In this paper, an attempt has been made to give in brief the exhaust emission controls of U. S. A. and Europe.

2. Automobile exhaust gas and air pollution

Although in one word it is known as air pollution, it is a highly complicated phenomena. Usually the smog that is seen is considered as the main problem and this is followed by a number of other problems created by substances which cannot be seen by eyes, for example SO_2, CO, NO etc.

2-1. Smog

When the atmosphere is clouded and the visibility is poor and besides there is a mist at a distance, such a condition is known as smog. However, there are two types of this smog. One is known as the London-type smog and the other type is known as the Los Angeles-type smog. As can be seen in Table 1, the time of origin, weather conditions, the reasons of formation of these types of smog are entirely different. All the accidents mentioned earlier were of the London-type smog and this type of smog occurs in various regions. However, the Los Angeles-type smog occurs mainly in the neighborhood of Los Angeles city and San Francisco Gulf of California State only.

The occurrence of London-type smog is not at all related to the automobile exhaust gas. It is only a combination of the smoke emitted from factories and houses and the fog. Even in the major cities of Japan, when the factories are closed for 3 days in celebration of the New Year, mountains which are at a far-off distance are seen very clearly as if they could be touched by hands. From this also it can be easily understood that this type of smog is only due to smoke and fog. In the case of Los Angeles-type smog the automobile exhaust gas plays an important role. This is caused by the photochemical reactions of NO_x and HC present in the atmosphere by the strong solar energy giving

TABLE 1

Types and characteristics of smog

	London-type smog	Los Angeles-type smog
General condition	Old natural phenomenon (smoke + fog)	New natural phenomenon (photochemical raction)
Components	Particulates, sulfur oxide, CO	HC, NO_x, ozone, PAN
Fuel source	Coal, petroleum	Gasoline, LPG
Climatic conditions		
Season	Winter	Summer, Autumn
Temperature	Low (below 4.5°C)	High (more than 25°C)
Humidity	High (rainy season)	Low (dry period)
Sunlight	Clouded	Strong and bright
Ozone level	Low	High
Time of formation	Day and night (continuous)	Only during day time
Visibility	Short (2-3 yards)	Medium (1/2 mile)
Damage to human beings	Much irrigation in throat (sometimes leads to serious illness and death)	Irrigation in eyes (effect on health not yet clear)

(According to Leonard Raymond)

rise to the production of ozone O_3, peroxyacyenitrate PAN and other secondary products which cause irritation to the eyes of the people because of their oxides. Moreover, these substances also badly affect the agricultural products and other plants. At the same time, they also spoil the gum, rapidly corrode the metals and cause pollution.

When a substance burns it gives rise to the production of high temperature and as a result N_2 and O_2 present in the air combine automatically forming NO_x (NO, N_2O, NO_2, N_2O_3.). This NO_x is also produced due to combustion in the engine of automobiles. Besides, hydrocarbons are produced in a number of processes such as burning of organic substances, burning of fuel, oil refinery, sale of petroleum, plastic industry, paint solvent, metal washing materials etc. Since petroleum undergoes combustion in the engine of automobiles (Table 2), HC is produced. In Los Angeles City, because automobiles are most commonly used as the public conveyance, there is considerably large emission of HC and NO_x from these automobiles. For example, about 50% of the total NO_x and about 70% of the total HC are said to be coming out from the automobiles. Hence, in order to restrict the formation of photochemical smog like this, the amount of NO_x and HC coming from the automobiles should be reduced at all costs.

For this reason, for the first time in the world, a regulation on the automobile exhaust gases was established in California in 1961. In spite of this regulation, the smog in Los Angeles City is yet to be reduced. Table 3 gives an idea of the number of days in a year in which the condition had exceeded the environmental standard. This table clearly shows that CO, NO_2, ozone and particulates have all crossed the standard level for a considerable number of days.

Among these, CO showed a slight decrease in value after the formulation of regulation in 1966. However, ozone and particulates which serve as an index for the photochemical smog showed gradual increase for continuous number of days although the regulation on HC had been formulated in 1961.

The generation of photochemical smog gives rise to the formation of ozone and whenever smog occurs, the visibility becomes poor because of the aerosols. The degree of smog can be calculated from the number of days when particulates have exceeded the environmental standard. The reason for the smog not clearing up can be understood from the Fig. 1. As is clear from Fig. 1, the irritation in the eyes which indicates the intensity of smog changes with the concentration of HC and NO_x in the atmosphere and when the concentration of HC and CO_x is made to decrease, NO_x shows an increase (vide Fig. 2). Thus, the conditions donot show any improvement. Consequently, in California State, a standard (described in Table 4) was set to rapidly decrease the concentration of NO_x.

TABLE 2

Source of HC and amount of emission (Los Angeles, 1967)

Source	HC gas ton/day		
	Activity		Total
	High	Low	
Petroleum (refinery, sale, production, etc.)	55	175	230
Chemical industries (sulfur, sulfur oxide etc.)	15	45	60
Mineral industries (materials of asphalt roof)	-	1	1
Organic solvents (surface paints, dry cleaning, grease remover	300	160	460
Fuel	-	9	9
Incineration	-	1	1
Automobile (gasoline-run, diesel-run)	1300	490	1790
Other transport (railways, ship, airplane)	18	20	38
Total	1690	900	2590

TABLE 3

Environmental standard of pollutants and actual state of pollution (Los Angeles, 1969).

Year	CO	NO_2	Ozone	Particulates
1960	20	112	236	180
1961	20	101	212	169
1962	19	85	225	211
1963	35	79	191	167
1964	19	78	179	131
1965	58	100	190	153
1966	22	87	214	173
1967	12	113	210	190

Environmental standard (1969)

CO ... the mean for 8 hours, 30 ppm and mean for 1 hour, 10 ppm

NO_2... mean for 1 hour, 0.25 ppm

Ozone... mean for 1 hour, 1 ppm and mean for 8 hours, 0.3 ppm

Particulates... amount equal to the condition when visibility becomes less than 3 miles at a relative humidity of less than 70%.

On the other hand, this type of photochemical smog is not found in European countries. This is owing to the fact that all European countries are found only on the Northern regions and the solar radiation is so poor that it cannot be compared with the solar radiation received by California. Moreover, the temperature is also low. Exhaust gases like CO etc. are increasing in London, Paris and other big cities, a condition which is almost resembling that of Los Angeles. However, the photochemical smog is quite different from the smog found in Los Angeles.

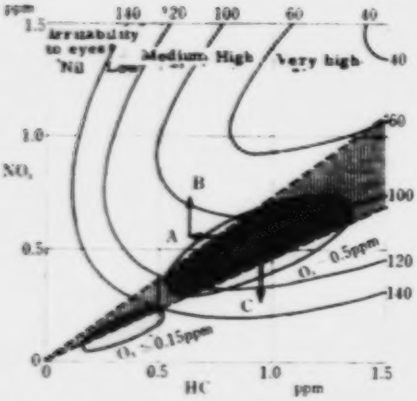


Fig. 1. Relationship between irritability to eyes and NO_x, HC in atmosphere due to photochemical smog (Los Angeles).

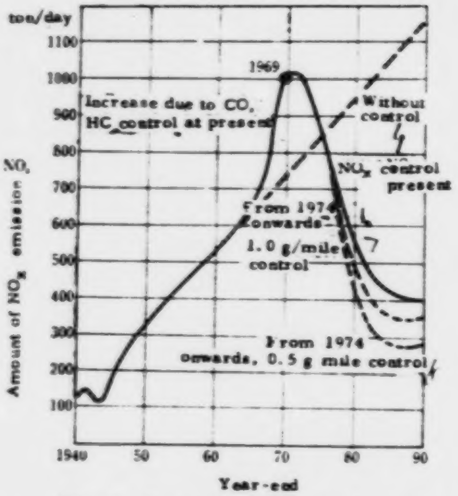


Fig. 2. Amount of NO_x emission and its control program.

TABLE 4

Exhaust emission control in automobiles in California State

	Gases under control	Vehicles under control	Control value 1965	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	Remarks
California State	CO	<6001 lb. >140 cuin	<1.5 %	50 – 100cu in<2.3% 100 – 140cu in<2.0%				<23g mile				<12g mile		
		>6001 lb.					<1.5%		<1.0%					
	HC Exhaust gas	<6001 lb. >140 cuin	<275 ppm	50 – 100cu in<410ppm 100 – 140cu in<350ppm				<2.2g mile		<1.5g mile		<0.5g mile		
		>6001 lb.					<275 ppm		<180ppm					
	HC Crank case gas	All vehicles	1961 model											
	HC Evaporating gas	<6001 lb. >50 cuin					<6g test							
	NO_x	001 lb. >50 cuin					<4g mile		<3g mile	<1.3g mile		<1.0g mile		
	Smoke	Diesel vehicles												Applicable in USA

2-2. Carbon monoxide

CO is a poisonous gas formed by incomplete combustion. Even in Japan many people die by CO poisoning in winter. CO is produced in large quantities from internal heating system as well as from fire. It is also produced from automobile engines. CO usually combines with hemoglobin in the blood and forms CO-Hb. This causes a decrease in O_2-Hb and thereby blocks the distribution of oxygen to various parts of the body. As a result there is a deficiency of oxygen in the body and normal physiological functions are impaired. If the deficiency is mild, the normalcy can be restored. But, if the condition is severe so as to affect the lungs, it becomes irrepairable. In Los Angeles, since the electricity and gas are mostly used as fuel in homes, 98% of CO in the atmosphere is said to be from automobile exhaust gas. In Japan, the method of calculating the extent of CO is not yet finalised and the method followed in America is followed for the time being. It seems that the major portion of CO in atmosphere comes from automobile exhaust gas. However, according to recent research[1] there is an increasing trend in the consumption of fuel oil for house heating and this has caused increase in the atmospheric CO. Hence the atmospheric CO in Japan is now suspected to come from oil burning.

The damage caused by CO is wellknown in every part of the world. In the city of Paris there are a number of monuments in different parts of the city and the main roads from various directions lead towards these monuments. As the crossing points are fewer than in Japan, traffic is very congested. The vehicles which pass these roads run both directions and some even take U-turns. During rush hours the roads become crowded and people are sometime found even to fall down at the sight of these eddies of vehicles some of which may even keep going round and round the monuments unable to cross the roads. The traffic control authorities at these points have a terrible time. A few years back a traffic policeman collapsed and was later found to be a victim of CO poisoning. It was only after this incident that the Paris Police Research Department studied the CO content of the air in these regions. They divided the whole city into 317 blocks. CO was measured in each of these blocks during peak traffic hours and a mean value was determined. As shown in Fig. 3 there is an increasing tendency in the mean CO concentration in Paris city.

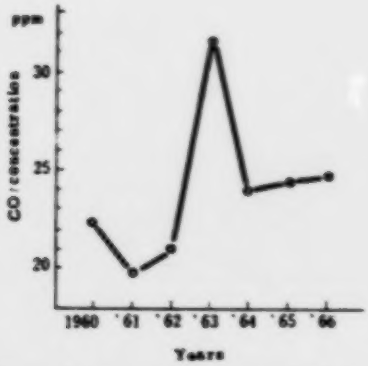


Fig. 3. Change in mean CO concentration in Paris City.

In West Germany also there have been incidents of CO poisoning among traffic police. Various other European countries have also come across such poisoning by CO. In Sweden CO has been measured regularly for the past 3 years. In Frankfurt also the University conducts periodical measurements of atmospheric CO. However, devices to measure automobile exhaust gas in relation to air pollution are yet to take final shape in European countries. The monitoring station in Japan has made much progress in this line. The efforts made by the Health Ministry in this field deserve appreciation.

2. 3. Oxides of Nitrogen (NO_x)

It seems that NO_2 is as poisonous as or more poisonous than SO_2. NO is only about 1/5th as poisonous as NO_2. About 95% of the oxides of nitrogen emitted from the automobile engines is NO and 4-5% NO_2. However, as NO gets oxidized in atmosphere into NO_2 it ultimately becomes dangerous.

The environmental standards for various pollutants were settled last autumn in California (Table 3). In this Table, NO_2 is shown to be less than 0.25 ppm for 1 hr mean value. But the same Table also shows that in Los Angeles City NO_2 exceeds the environmental standard for 1/5th of a year. Thus, it is necessary to enforce the regulation for NO_x in California State.

In Bonn of West Germany, the exhaust control for NO_x is worked out by converting NO_x into NO_2 as in the case of SO_2

emitted from factories (Table 5). In Japan too, NO_2 is on a very high level and it seems that in addition to automobiles, factories are also sources of NO_2 emissions. However, this requires further studies[2].

TABLE 5

Emission control in factories in West Germany

Pollutants	Emission limit	
SO_2	0.4 mg SO_2/m^3 (average for 30 minutes)	0.75 mg SO_2/m^3 (average for 30 minutes and once in 2 hours)
NO_x (converted to NO_2)	1 mg/m^3 (average for 30 minutes)	2 mg/m^3 (average for 30 minutes and once in 8 hours)

2.4. Particulates

Particulates are one of the major factors causing smog. A large amount of particulates are found in automobile exhaust gas (Table 6). A major part of particulates seems to be lead oxide owing to the presence of lead alkyl added to gasoline. While lead is present even in food stuff and is swallowed in minute quantities by man, if the quantity is large it gets precipitated in the human system and causes damage. The minute quantities of lead present in atmosphere have not yet been found to cause any major damage to human beings. Also, it cannot be said that particulates of the exhaust gas are the sole factor causing smog. However, in America, particulates are also included in the list of pollutants to be regulated from 1975.

3. Exhaust Emission Control of USA

Los Angeles City has been a victim of exhaust emission for the past 20 years. Hence the efforts made by American

TABLE 6

Source and amount of particulates (San Francisco, 1964)

Source	Particulates (ton/day)
Petroleum (refinery, Sale, Production, Supply)	11.5
Chemical industries (chemicals, eatables)	28.1
Mining industries (steel, non-ferrous, furnaces, driers and ceramics)	23.9
Organic solvents (surface paints, grease remover, dry cleaning)	4.9
Fuel (domestic, shops, factories, refineries)	19.0
Incineration (domestic,shop, wood)	32.4
Agriculture (fruit garden, wheat, miscellaneous plants)	15.8
Transport (gasoline-run, diesel-run, railways, ships and airplanes).	63.7
Total	About 200

Government to check the pollutant as well as the capital invested for implementing the controls is far more than it is in Japan. The annual budget for the year 1970 to check CO, HC, NO_x and particulates emitted from automobiles is $ 23500000. Further $ 29800000 for the same year is budgetted for developing power engines for new automobiles other than gasoline run engines. In other words, a total of $ 53300000 is meant for controlling pollutants and this amount is far greater than the amount budgetted in Japan. It is likely that this capital investment will be doubled in 1972.

(1) Plan for reducing exhaust emission: Table 7 shows the control plan for exhaust emission made by United States Government and a comparison with the plans made by other countries. It shows that according to this plan the USA Government wishes to reduce the exhaust emission in 1975 to half of what it is in 1974, and by 1980, half of what it is in 1975. Although the plans are yet to be approved by the US Senate and it is only a model, it is appreciated that it is the best plan to make the automobile exhaust gas completely safe. While it will cost $ 200-300 per vehicle to implement the control and achieve the aim for 1975, because this type of converting the exhaust emission into a harmless state is necessary and the people are likely to accept the plan.

(2) Technical measures: Although it is a difficult subject to study the technical aspect of converting the exhaust emission into a harmless state, the following steps are being considered on the basis of various researches conducted so far.

(i) Technical measures up to 1974: Technical measure to control the exhaust emission so as to achieve the level meant for 1974 (Table 7) will be brought about by modifying the engines of almost all the vehicles. Modification of the engine here means an engine which will be capable of complete cumbustion resulting in minimization of the pollutants.

CO and HC pollutants arise from incomplete combustion. As shown in Table 8, they influence the exhaust emission to various extent depending upon the conditions of the engine. Hence the engine should be modified carefully to reduce the emission of CO and HC. However, the same Table also shows that the method to decrease CO and HC always leads to a condition where NO_x becomes higher in value. This is because NO_x forms rapidly at high temperature. But combustion at high temperature decreased the incomplete combustion of CO and HC. Thus, it is very difficult to device a method by which all the pollutants of exhaust gas can be uniformly reduced. However, while carefully studying this type of contradictory

TABLE 7

Exhaust emission control in USA (excepting California State)

Name of country	Gases under control		Vehicles under control	Control value 1966	'67	'68	'69	'70	'71	'72	'73	'74	'75	'80	Remarks
American regulations	CO		<6001 lb.		1.5										
			140 cu in	[illegible]	[illegible]	[illegible]		[illegible] g mile				11g mile	[illegible] mile		
			>6001 lb.			1.5									
	HC	Exhaust gas	<6001 lb.		275ppm										
			140 cu in	[illegible]	[illegible]	[illegible]			2.2g mile			[illegible]g mile	0.25g mile		
			>6001 lb.			275ppm									
		Blow-by gas	[illegible]		0										
		Evaporating gas	<6001 lb.	6g test											
	NOx		<6001 lb.						3g mile		0.9g mile		0.4g mile		
	Particulates		<6001 lb.								0.1g mile		0.03g mile		
	Smoke		Diesel-run vehicle												
Japanese regulations	CO		Small-size vehicles	3.0		2.5			Idling (Old vehicles), less than 5.5%);(new vehicles less than 4.[illegible]%)						
	HC blow-by gas		Small-size vehicles												Apparatus fitted
	Smoke		Diesel-run vehicles												
ECE regulations (Europe)	CO		< 3.[illegible]						Includes idling						Expected
	HC		< 3 [illegible]						Includes blow-by gas						Expected
	Smoke		Diesel-run vehicles												Under investigation

effects it is possible to device an efficient method by which CO, HC and NO_x can all be brought down to a lower limit. This level is to be achieved by 1974. A majority of the engines require a special equipment to reduce emission of HC at the time of slowing down. In some of these vehicles there is either electronic spray groove device provision to take care of this aspect.

(ii) Technical measure for 1975 control: According to this measure the pollutants are to be reduced to half of what they are in 1974 and at the same time control of particulates is to be enforced. As shown in Table 7, if particulates are to be checked, the particulates removing equipment now being tried out (cyclone type or filter type) may not be effective. Hence a device should be found which would prevent the emission of particulates in exhaust emission. The Government of USA is trying to overcome this problem by prohibiting the use of lead as an additive to gasoline.

In order to increase the octane value of gasoline the easiest way is to add lead alkyl as tetraethyl lead and till now this has been the practice. USA is planning to limit this addition to 0.5 g per gallon in 1973 and gradually bring it down to zero in 1975. While it is possible to satisfactorily check the particulates, it will of course have some undesirable influence on the engine. The first disadvantage will be the decrease in the octane value. Although it is not that there is no better material or better way of thermal decomposition to replace lead alkyl for the maintenance of the octane value, it is feared that the cost of gasoline will rise considerably. At present the octane value of materials other than gasoline is only 3-4. Again the output of engines of low compression ratio will be low and the fuel consumption may also be unfavorable.

In spite of all this concern over the influence on the engines, the automobile makers of America are still in the opinion of removing the lead processing of the gasoline. This is because of the fact that in this way not only the problem of particulates can be overcome by this method, but it will also be technically possible to develop automobiles emitting much lower pollutants by 1975. The following will explain the other reasons:

(a) Life of catalyst gets prolonged: CO, HC and NO_x can be easily converted to harmless gases by using catalyst. The catalyst loses half of its effectiveness after 5000-10,000 km run. This is because the lead oxide from lead alkyl added to the gasoline adheres to the surface of catalyst and blocks its activity. Lead-free gasoline keeps the catalyst fully active and hence it will be possible to achieve the control unit aimed for 1975 and bring down the pollutants in automobiles.

(b) Life of the manifold reactor is prolonged: one of the methods to decrease CO and HC without using catalyst is to apply the manifold reactor. In this method a large reacting

TABLE 8

Relationship between change in conditions and pollutant emission in gasoline-run engine

Factors	Degree of influence		
	CO	HC	NO_x
Use of diluted air-fuel ratio	Reduction.... effect prominent	Reduction... effect prominent	Increase... effect prominent
Delay in spark time	--	"	Reduction "
Reduction in combustion chamber area/volume ratio	--	" medium	Increase poor
Removal of sediments from combustion chamber	--	" "	Reduction "
Increase in the number of engine rotations	--	Reduction... effect prominent . .	Increase mediun
Increase in engine load	--	" poor	" poor
Increase in cooling water temperature	--	" "	" medium
Increase in engine pressure release	--	" "	Reduction poor
Increase in engine compression ratio	--	Reduction... effect prominent	Increase increase

chamber is attached to the exhaust exit and the exhaust gas is mixed with secondary air at high temperature by using a pump. By this method CO and HC are oxidized slowly. The control value of 1975 can be achieved by this method. If lead alkyl is added to gasoline, the material of reactor (ceramic or stainless steel) is affected at high temperature and in its absence the material remains unaffected.

(c) Checking of damage by lead on the basis of exhaust gas circulation method: without using catalyst, NO_x is reduced and a part of the exhaust gas is reabsorbed. The formation of NO_x is reduced by lowering the combustion temperature. Even in this method, if lead is added to gasoline the passage becomes blocked and the durability becomes poor. This method can be applied by avoiding lead alkyl.

(d) Other measures: when lead or carbon accumulates in the combustion chamber, HC and NO_x increase. The condition of the combustion chamber is restored only when such accumulation is removed. Lead-free gasoline considerably reduces such accumulation in combustion chamber. Thus, the formation of H and NO_x is reduced and at the same time the damage to ignition plug is also checked and the life of exhaust gas system such as muffler is prolonged.

Three types of low pollutant vehicles as shown in Fig. 4 can be considered on the basis of using lead-free gasoline. The best among these types will be selected on the basis of economy, efficiency, and durability. Type A is manifold reactor model and types B and C are both catalyst model and with recirculation of exhaust gas.

(iii) Technical policy to achieve plan for 1980: the plan for 1980 aims at making the automobiles completely free from pollutants. However, the question now is whether it is necessary to go to that extent. Even in California State, the pollution by exhaust emission is expected to be completely removed on the basis of 1975 control. In fact, the control in this State is not being made more intensive. However, it will become an epoch if America achieves the point of no-pollution from automobiles. Technically speaking this seems to be possible.

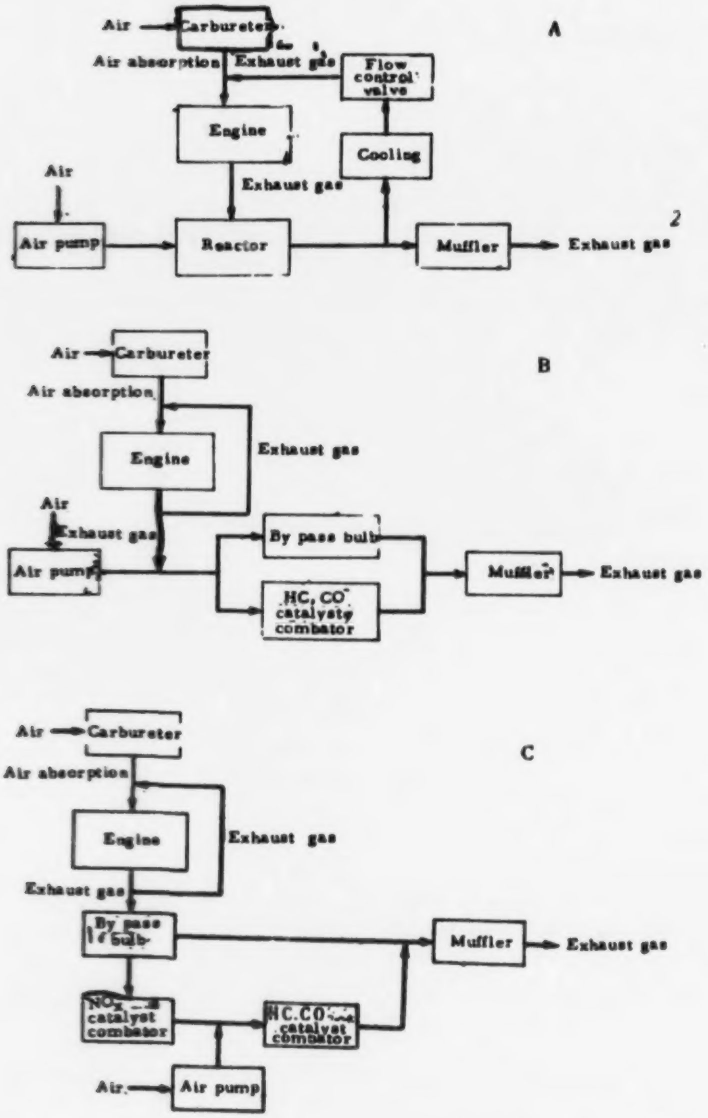

A
Air
Carbureter
Air absorption
Exhaust gas
Flow control valve
Engine
Cooling
Air
Exhaust gas
Air pump
Reactor
Muffler
Exhaust gas
2
B
Air
Carbureter
Air absorption
Engine
Exhaust gas
Air
Exhaust gas
Air pump
By pass bulb
HC, CO catalyst combator
Muffler
Exhaust gas
C
Air
Carbureter
Air absorption
Engine
Exhaust gas
Exhaust gas
By pass bulb
Muffler
Exhaust gas
NO_x catalyst combator
HC.CO catalyst combator
Air
Air pump

Fig. 4. Layout of exhaust gas processing apparatus.

(a) Gas turbine: It is an engine in which the air is compressed by a revolving compressor and fuel is blown into the combustion chamber. By using the course of combusted gas whose volume has increased, the turbine is rotated and kinetic energy generated. Since no such compression is expected in the rotary compressor the heat efficiency is low and unless it has a high output gas turbine, the fuel consumption factor will be unfavorable. However, since it is possible to combust at a high air-fuel ratio (weight ratio between fuel and air), the combustion temperature is low as also there is complete combustion of CO and HC. In addition, formation of NO_x is low. Hence this method might achieve the level meant for 1980. A large scale test is being carried out in America and in fact the day is not far off when the method will be applied to high-speed buses and trucks.

(b) Hybrid engine: It is possible to decrease the pollutants by 1/3rd by using catalyst etc. in the case of gasoline engines provided extreme driving conditions like acceleration or slowing are not applied. Under these conditions it is also possible to achieve the goal of 1980. It seems that by starting power engine at normal load and speed and driving the vehicle on the basis of motor run by electric energy the type of vehicle aimed for 1980 could materialize by using the accumulated electric energy in the batteries at the time of speeding. That is what is known as hybrid engine.

(c) Battery automobile; In this type of vehicle the driving is done by a motor using electric energy accumulated in the battery. No pollution arises from this vehicle. However, the problem still remains as to the source from which the electric energy is to be accumulated in the batteries. If the electricity is to be derived from power stations, the pollution will only increase. If nuclear power is to be utilized it would mean greater danger in the form of radiation. Again there is also the problem of the amount of stored energy and so far no source has been found to be equal to the existing engines in automobiles as far as speed and running distance are concerned.

(d) Electric automobile: Automobiles to be run by current electricity are also being considered but practical ideas are yet to come out.

(e) Steam engine: America suggested the possibility of using steam engines. However, the difficulties related to servicing, safety and cost are well realized.

(f) Others: There are the external cumbustion engines like stalling engines which have already been tried out. However, many points are yet to be clarified as to its applicability in automobiles. The cost of new engine has to be well worked out and it seems that it would be about 2-3 times more than the usual price.

4. Exhaust Emission Control of Europe

Compared to the activities related to pollution control in America, the pace in Europe is much slower. The main reason for the slow pace is that the pollution in Europe is increasing only slowly and so far no major damage from automobile exhaust has been felt. However, the exhaust emission regulations implemented in America and Japan have inspired Europe and moreover the exhaust emission regulations of the buying countries have to be accepted as far as the export models are concerned. Hence measures to check exhaust emission are being studied.

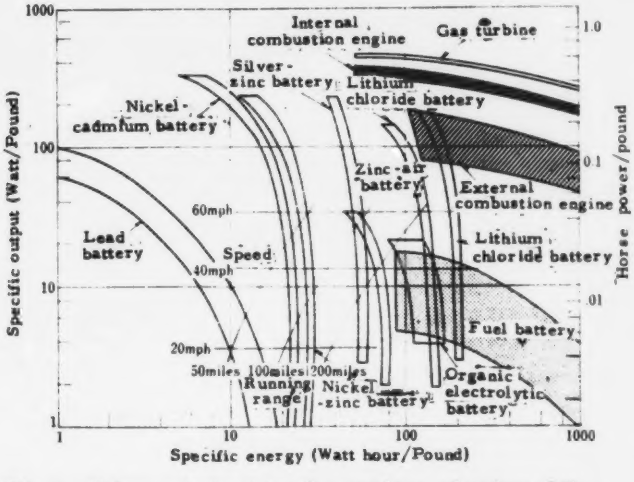


Fig. 5. Nature of checking the engines of automobiles.

Again CO is recognized as a harmful gas and measures to control its emission in the exhaust gas are under study. Since the European land mass is continuous and connects several countries, the automobiles are freely running as international model in various countries. If the exhaust emission regulations are different for each country, it may give rise to several complications. Hence it is intended to formulate a uniform exhaust emission control under the Economic Commission for Europe (ECE). The clauses of exhaust control (vide Table 7) have been prepared but they are yet to be recognized by the various countries. At present individual exhaust emission control is being applied in some parts of Europe.

4.1. Common Consideration of Various Countries

All the countries of Europe believe that photochemical smog of the type found in California State will not form in Europe. Hence, they feel it is unnecessary to formulate control. However, HC is one of the main factors for causing bad odor, and while decreasing CO the increase of HC should also be checked. In view of this fact HC control has to be considered to some extent. NO_x is not even in the list of exhaust control meant for consideration.

In fact, in Europe visible pollutants are given more importance than invisible pollutants. Europe is firstly planning to check the black smoke and bad odor emitted by diesel engines which are harmful to the sensory organs of human beings. There are many countries in Europe which have already implemented the regulations relating to diesel smoke. While there are many countries where the checking is done at the time of manufacture there are also countries like England where the checking is also done in the streets.

In England smog is also formed by coal combustion. In London, room heating is now done not by coal burning but by electricity or gas and this has greatly reduced the smog. The difference in the condition of smog can be well recognized when the conditions are compared with those found about ten years back. This became possible because the checking was carefully carried out according to plans and with government aid.

4.2. Regulations in France

In France the blow-by gas regulation has been carried out from September 1, 1966. The gas is used to remove the bad odor of HC emitted from crank case, and hence its use to control evaporating substance (from gasoline tank or fuel system) is also being studied.

As a measure to control CO, decrease of CO at the time of idling is applied since September 1, 1969. As shown in Fig. 6, when CO is reduced at the time of idling, there is also a reduction in CO at the time of slowing. However, the checking is not done when the vehicle is about to leave the factory but after it had run for 500 km. It is adjusted within 4.5% + 1%. This is because in the case of new vehicles, the engine is yet to be adjusted and the idling conditions can vary to a great extent.

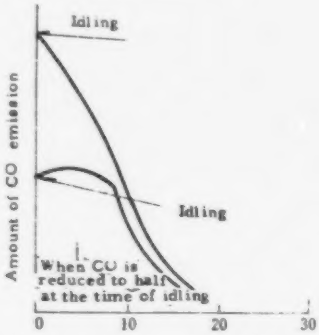


Fig. 6. CO emission after reducing CO at the time of idling.

It has been planned to implement ECE regulations relating to CO and HC of exhaust gas in the new model engines of September 1971 and newly manufactured engines of September 1972. Diesel smoke control has already been implemented since January, 1, 1964.

4.3. England

The diesel smoke control has been implemented since M 31, 1967. Diesel smoke is emitted when there is excess flow fuel or when there is faulty nozzle. It is possible to decrease the smoke by adjusting these parts. America has reported the use of barium additives to reduce diesel smoke.

Compared to Japan, traffic congestion in London does not differ much as far as exhaust gas is concerned. The mean value of CO taken for 8 hours is below 50 ppm and is below the standard value. It seems that CO and HC control are not immediately required in London.

West Germany

Blow-by gas control has been implemented since January 1, 1969. CO control during idling (within 4.1% + 1%) has been applied since July 1, 1969. Control of CO and HC of exhaust gas is to be applied from September 1, 1970.

4.5. Sweden

Diesel smoke control has been applied since December 13, 1968. Although the spray pumps have to be approved by the Ministry of Transport, exhaust emmision control is yet to be applied. CO control during idling is expected to be implemented from July 1, 1970 and control of CO and HC are to be applied from November 1, 1970.

5. Post Script

In this article, the exhaust emission control and policies relating to it made in Japan are not discussed. It was Japan which for the first time initiated the exhaust emission control and has continued to make it more intensive in the following years. The control was applied even to old vehicles. Even in America the old vehicles are in their original form. The exhaust emission control of Japan is the best devised so far and in future the methods to control exhaust emission are expected to show good results.

Note (1) Yagyu (National Hygiene Research Center of Tokyo): Air Purification Vol. 7 No. 5, 1970.

(2) Air pollution Research Center of Tokyo: Outline of the results of measuring air pollution, March, 1970.

Kohayakawa: Internal Combustion vol. 8 No. 19, 1969.

Yoshida et al.: Journal of Medicine (Mie Prefecture), Vol. 12 No. 1, July 1968.

EXHAUST GAS OF THE AUTOMOTIVE DIESEL ENGINE

M. OKA

1. Introduction

Recently, air pollution is pointed as a serious social problem and several measures to prevent it are carried out in various fields. The dangerous consequences of air pollution were first noticed in 1952 in what is known as the great London Smog. The important factors behind the event were smoke and sulfurous acid gas emitted by the air conditioning equipments fitted in houses, buildings and factories. The end of the Second World War brought about a rapid development of modern factories and along with the increase in the number of automobiles there has been a rapid increase in the amount of automobile exhaust which is now one of the main source of air pollution. Measures to check the same are being studied. Regarding carbon monoxide present in the exhaust gas of gasoline automobile, a law has been enforced since September 1966 to control the concentration of this gas. Measures to bring down this concentration are also being studied. In the case of diesel vehicles, Europe and America are trying hard to check the black smoke. Japan too is concerned with diesel smoke and the diesel smoke of latest engines is required to be above 7.0 in the Mansel color scale at the time of model approval test.

In February last, the environmental standard has been defined on the basis of carbon monoxide. This clearly showed the Government's concern over the air pollution. It is also reported that there is a long term plan regarding the control of automobile exhaust gas.

The following is an account of the various countermeasures to check the pollution caused by diesel exhaust gas, the data for which are collected from both in and outside Japan.

2. Components of pollutants in diesel exhaust gas and the mechanism of their formation(1)

The following are the pollutants found in diesel engine exhaust gas:

(1) Smoke (2) Carbon Monoxide (3) Nitrogen oxides
(4) Hydrocarbon (5) Sulfurous acid gas (6) Odor

The burnt products and unburnt fuel compounds differ from the products of gasoline engine. The difference between the two is because:

(1) The fuel used is different. The H-C system in diesel is heavier than in gasoline and the evaporation is slow.

(2) The principal of operation, that is the combustion cycle differs. In the case of gasoline engine, the output is regulated by varying the booster pressure by turning the valve. Moreover, the mixture is uniform as that of air combustion rate (around 15:1) which is very near the theoretical mixing ratio. By allowing electric sparks in this mixed gas, a very efficient fire is caused automatically. In the case of diesel engine, the booster pressure is not adjusted by the screw valve but by adjusting the fuel amount. Hence, the air combustion ratio differed according to the load and the ratio was on a wide range of 20:1 100:1 in the combustion chamber. Moreover, since it is compressive ignition, the ignition source may be present in any part of the combustion chamber. The pollutants formed in the diesel engine become diluted due to excessive air by the time they come out as exhaust gas.

Usually, the design of combustion chamber and the types of fuel control system in the gasoline engine are fewer than in diesel engine. Since the diesel engine is a combination of combustion model (precombustion chamber, direct jet type), air absorption type (non-supercharge, turbo supercharge, supercharge) etc., it is difficult to describe the pattern of emission.

2.1. Smoke(2, 3, 4)

The smoke of diesel engine can be broadly divided into the following types:- (1) Black or grey smoke (usually known as black smoke) and (2) Blue-white smoke. It is the black smoke which is of special interest in the study of air pollution. The black smoke or the formation of soot is greatly influenced by the ratio of fuel-air and it shows rapid increase when the load increases and the air supply is poor.

The diesel engine differs from gasoline engine and the amount of air mixed in the combustion chamber is not uniform. There is local concentration of fuel/air. Usually, when the ratio of fuel-air is more than 1.5 times of the theoretical mixing ratio, the soot forms in the early stage of combustion cycle in some places of combustion chamber due to high pressure. The formation of soot differs according to the local ratio of fuel-air, types of fuel and the pressure in the combustion chamber. Unless the soot is to burn within the combustion cycle period providing enough oxygen, it comes out as smoke. It has been said that the granule-size of soot is in the range of 0.01-0.04 μ diameter. However, larger granules have been reported and those appear to be an accumulation of smaller granules

Fuels of the petroleum system are a combination of carbon and hydrogen in the form of hydrocarbon. Since the number of carbons in the light oil used in diesel engine is higher than in gasoline, the temperature of naturally ignited fire is low. When heavy and light oil having larger molecules are heated, there is a liquid phase decomposition before evaporation whereby carbons are left. The progress of decomposition depends upon the fire formation and the speed of combustion. It is also related to the formation of soot and smoke. The mechanism of combustion of high hydrocarbons includes the repeated decomposition and localized oxidation followed by continuous chain reaction or branched chain reaction in which free atoms and free radicals are freed. Hence there is a difference in the combustion of mixed gases in the gasoline engine and the diffused combustion in the diesel engine. Usually, in the case of gasoline engine, the soot and smoke are less even when the air supply is poor. The unburnt part of CO and H_2 left as residue can be determined on the basis of equilibrium constant $K = \frac{[H_2O][CO]}{[CO_2][H_2]}$. In the case of diesel engine much soot and smoke is formed owing to inadequate supply of air.

Regarding the mechanism of soot and smoke formation, it is not always clear but the following description is given. The formation of C-C chain is usually seen in the high temperature reaction layer of hydrocarbon. But in the case of gasoline engine, since the fuel and oxygen are firmly combined by their molecules, $C_2 + 2H_2O$ becomes $2CO + H_2$ due to the action of H_2O as a catalyst. The combustion of CO and H_2 then proceeds. On the other hand, in the case of diesel engine, the diffusion speed of oxygen is restricted and the formation of H_2O is delayed. Moreover, the decomposition is accelerated because of localized high temperature and the formation of C-C is rapid. Owing to C-C polymer, carbon granules are formed. The formation of soot and smoke depends upon the type of fuel; it is minimum in the case of paraffin system of hydrocrabon and maximum in aromatics and naphthene system. Usually, the soot and smoke formation is high when C/H is high.

2. 2. Carbon monoxide(2)

The concentration of carbon monoxide in the exhaust gas of diesel engine is very much lower than that of gasoline engine. It does not seem to be the major cause of air pollution. The concentration of carbon monoxide formed from fuel gas depends upon the ratio of air combustion and when the air combustion ratio is beyond 18, it is only a few decimal percentage.

2. 3. Nitrogen oxides(5)

As oxides of nitrogen, N_2O, NO, NO_2, N_2O_3, N_2O_4, N_2O_5 etc. are known. Oxides of nitrogen liberated from automobile exhaust gas are mostly in the form of NO and only a small quantity of this is in the form of NO_2. When N_2 and O_2 in the air absorbed in the combustion chamber react at a combustion temperature of about 800°C, they combine in the form of NO, NO_2 and other forms of oxides. NO liberated into the atmosphere reacts with oxygen present in it and becomes NO_2.

$$N_2 + O_2 \rightarrow 2NO$$
$$2NO + O_2 \rightarrow 2NO_2$$

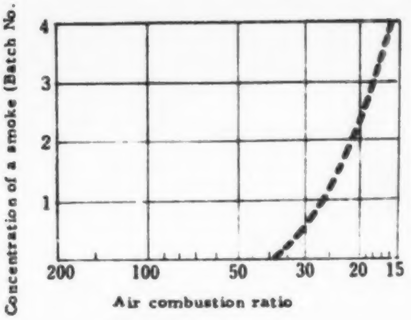


Fig. 1.

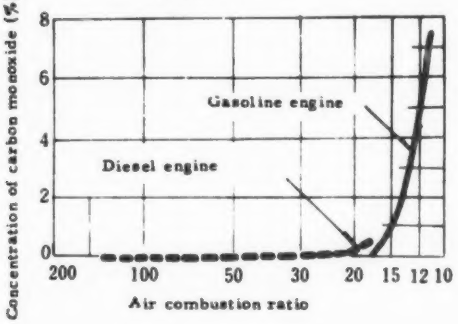
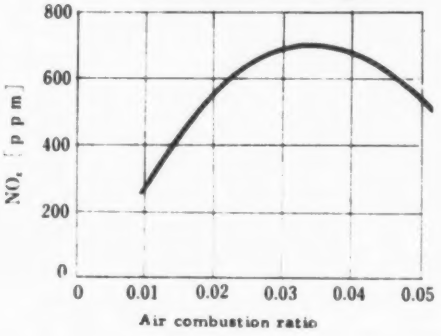


Fig. 2.

The results of the observations carried out by H. K. Newhall and E. S. Starkman on the single air duct engine reveal that NO is released in an unbalanced chemical condition and this is not because of heat degeneration.

Regarding the mechanism of the formation of oxides of nitrogen in the combustion chamber of diesel engine. G. McConnel took the direct spray engine for his studies and gave the following explanation. During early stage of combustion, a few independent sparks occur within the compressed "air pockets" which is moving at a constant swerling movement. Along with the progress in combustion, the oxygen present in "air pocket" surrounding the nucleus of the spark, is rapidly utilized. Hence, the part of "air pocket" rapidly separating from the fuel drops and maintains the early oxygen concentration. It becomes heated owing to (1) increased compression force and (2) heat conducted from sparks. Under this condition, a fairly high concentration of oxy-



Engine . . . 4.5" PC type single duct

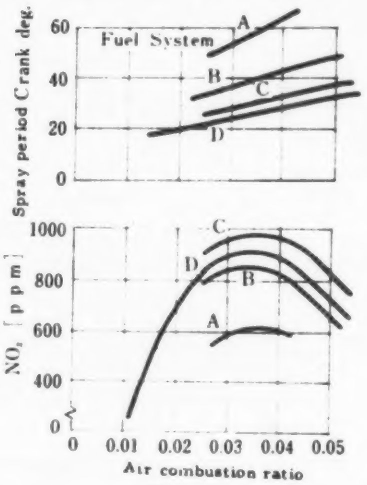
Number of rotations . . . 1200 rpm

Spray period . . . BTC 5°

Temperature of absorbed air 90°F

Manifold pressure - 60" Hg abs.

Fig. 3.



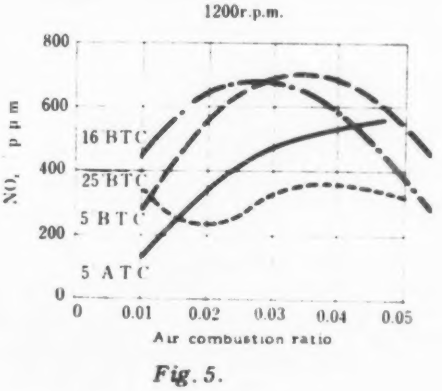
Engine . . . 4.5" PC type single duct

Number of rotations 1800 rpm

Temperature of absorbed air 190°F

Manifold pressure 60"Hg abs.

Fig. 4.



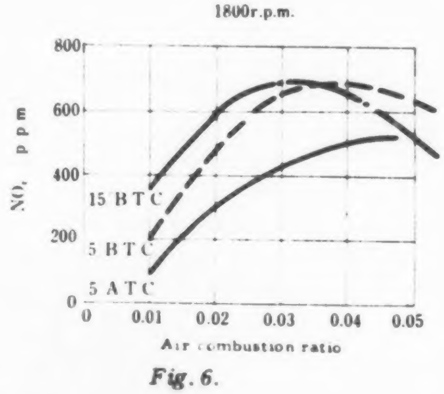
Engine . . . 4.5" PC type single duct

Number of rotations 1200 rpm

Temperature of absorbed air 90°F

Manifold pressure - 60" Hg abs.

Fig. 5.



Engine . . . 4.5" PC type single duct

Number of rotations 1800 rpm

Temperature of absorbed air 90°F

Manifold pressure - 60" Hg abs.

Fig. 6.

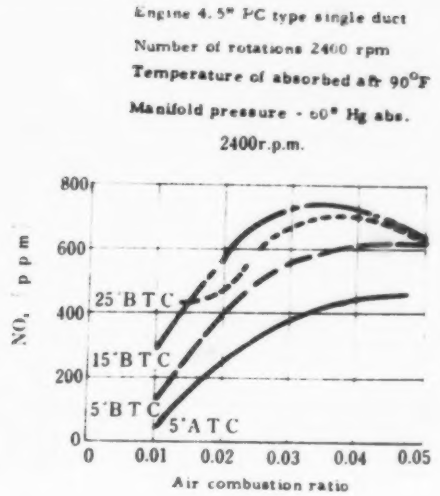


Fig. 7.

gen exists along with N_2 and moreover. it is subjected to a temperature of more than 1200°C. Thus, there appears a condition favorable for the formation of NO and NO_2. When the combustion is progressing, the proportion of "air pocket" in the combustion chamber decreases rapidly and in spite of the increasing gas temperature the increasing rate of nitrogen oxides becomes slow. Hence, it seems that the amount of oxides of nitrogen found in the exhaust gas is the product of a relatively rapid combustion process. When engine is worked at a high value of net mean effective pressure, the duration of combustion tends to become longer than when the net mean effective pressure is low. When the combustion is about to be completed, there is a shortage of oxygen and consequently there is a decrease in the formation of oxides of nitrogen. Moreover, since a relatively high temperature is maintained by the sparks, the degeneration of oxides of nitrogen already formed is also assisted. Hence, the absolute value of oxides of nitrogen present in the gas during the time when the combustion is about to be completed decrease due to the correlation between the degeneration and formation.

2.4. Hydrocarbon(4)

Hydrocarbons present in the exhaust gas are the so-called unburnt hydrocarbons and become changed into compounds of

Engine 4.5" PC type single duct
Number of rotations 2400 rpm
Spray period BTC 11°
Manifold pressure 60"Hg abs.

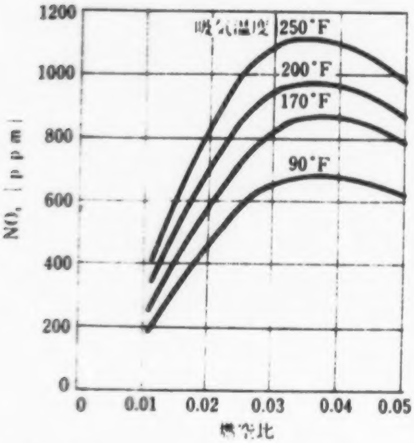


Fig. 8. Engine 4.5"PC type single duct; Number of rotations 2400 rpm. Spray period BTC 11°.

Engine 4.5" PC type single duct
Number of rotations 2400 rpm
Spray period B T C 11°
Manifold pressure 60"Hg abs.

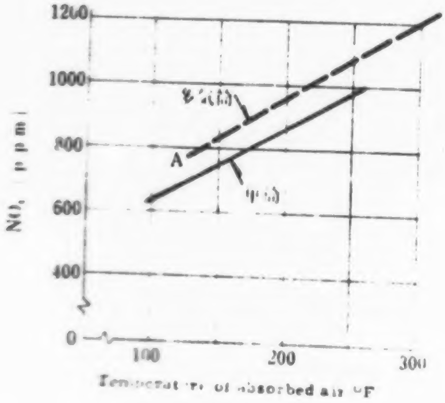


Fig. 9.

hydrocarbons depending upon the condition of combustion. This process is influenced by the components of the fuel. However, the extent of influence from the chemical components is not yet clear. The main aim to control the hydrocarbons is to decrease the photochemical smog. The photochemical smog reaction is a combined reaction of sun-rays, NO, and a particular type of hydrocarbons. Usually, hydrocarbon in the polluted air is considered to be harmless. But the experiments carried out on animals have revealed that the polynuclear aromatic substance (PNA) causes cancer. However, its effect on the human beings as an air pollutant is not yet clear.

The concentration of HC in diesel exhaust gas is smaller than that in gasoline vehicles and since there is no evaporation of the fuel at normal temperature, it need not be considered as a big problem.

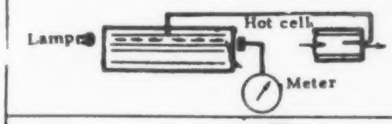
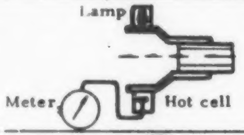
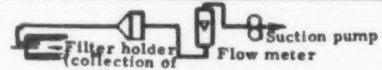
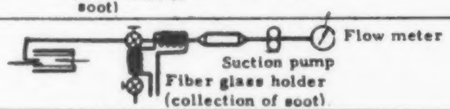
2.5. Odor(4)

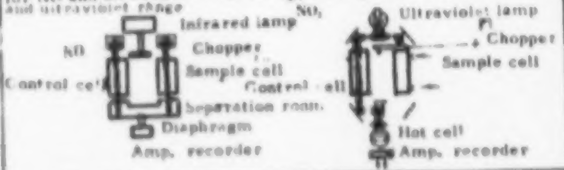
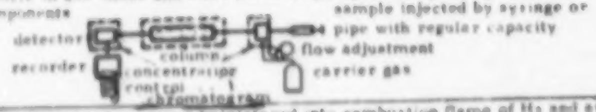
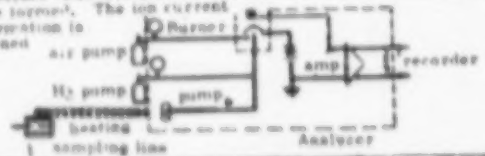
Regarding the characteristic odor of diesel engine nothing much can be discussed as any color depends upon the olfactory sense. Hence, the factors related to odor are not clearly understood. However, combustion of gasoline engine is of uniform consistency and the combustion of diesel engine is of different substances and the quality of odor emitted by these two engines is related to their respective components. The strength of odor is probably related to the fuel system and the type of fuel used. The parameter to measure the strength of odor is still under experimental stage and at present the strength could only be judged by human nose.

3. Method of analysis and measuring instruments(9-12)

The exact method of measuring the contents of diesel exhaust gas is yet to be confirmed. When a comparative study is carried out on the level of exhaust gas components and measures to control them are applied, it is necessary to measure them with the same parameter. If the method of measurement and the equipments used for analysis are different, the results would also be different. Hence, it is very important to confirm the method of analysis and the method of measurement which should be applied. The method and the instruments normally used at present are given in Table 1.

TABLE 1
General view of analytical methods and measuring instrument

Components	Measuring instruments	Analytical methods and principles		Remarks
Soot and smoke	Liquid extraction type instrument	Filter method	Sample collected in a cylindrical paper	Judged by comparing with Mansel color standard
	Bosch Model Smoke meter			Readings taken from photochemical reflection meter
	Von Brand smoke meter		Sample collected in a tap like filter paper	
	Hatridge smoke meter	Photo permeation method		Registered in recorder of readings taken directly
	PHS model smoke meter Beckman Smoke meter			Registered in recorder
	Caterpillar Soot Concentration Method	Measuring of solvent	 Filter holder (collection of soot) Suction pump Flow meter	Weight of the filter paper in which the smoke is collected, is taken (dry weight)
	Ethyl Soot Concentration Method		 Flow meter Suction pump Fiber glass holder (collection of soot)	Smoke collected is burnt and the concentration of smoke is determined from the volum of CO_2 (mg/ft^3, 60S, 30mHg).
	Ringelmann Method	Method of evaluating vicinity	Ringelmann Charts	Number 1, 2, 3, 4 determined according to the judgement by two persons.
NO, NO_2, NO-NO	Discontinuous method (chemical analysis)	PDS method	Samples of oxides of nitrogen were oxidized by the hydrogen peroxide of the absorption liquid into nitric acid. This was allowed to react with phenol disulfonic acid and coloration appeared. The formation of color was measured by using calorimeter and the amount of NO_x was determined by quantity detecting lines.	The duration of analysis is long. For complete absorption it takes 24 hours but it is possible to reduce the time to two hours
		Saltzman method	NO_2 measurement: sample NO_2 gas was passed in acetic acid solution including N (1-naphthyl) ethylene diamine chlorate and sulphanyl acid. The formation of color was measured with 7/J calorimeter (ultraviolet spectrometer) and the standard color ratio was determined. NO measurement: since N (1-naphthyl) ethylene diamine chlorate does not react with NO, it was first passed into a solution of potassium permanganate in nitric acid whereby it was oxidized. After its becoming as NO_2, some measurements were followed as carried out in the case of NO_2 measurements.	Recently this was modified

	Continuous analytical method	NO: ultra-violet analytical method NO_2: ultra violet analytical method (NDUV)	Concentration of particular components in the gas mixture sample was determined by measuring the difference in infrared energy for NO and difference in the energy absorption of visibility range and ultraviolet range  NO NO_2 Infrared lamp Chopper Sample cell Control cell Control cell Separation room. Diaphragm Amp. recorder Ultraviolet lamp Chopper Sample cell Hot cell Amp. recorder	This can be called as continuous absorption and the dead time differs according to the structure of sample line. Especially, in the case of diesel exhaust, it is necessary to be careful about moisture
HC	Gas chromatography (components separating method GLC)		Principle of analysis for HC to use the difference in the distribution of HC sample in gas phase and fixed phase (liquid phase) depending upon the components  sample injected by syringe or pipe with regular capacity detector recorder column concentration control chromatogram flow adjustment carrier gas	On the basis of detecting line already determined, the B of the reading or the area should be brought to original value. FID is used in the detecting vessel. It is very important to decide the correct column and control temperature.
	Hydrogen spark ionization method (FID (as total HC))		When hydrocarbons are administered into combustion flame of H_2 and air, ions are formed. The ion current transmigration is determined  Burner air pump H_2 pump pump amp recorder heating sampling line Analyzer	The temperature control of sample line and the temperature control inside the analytical meter are very important. By these, the extent of carbons to be
	Ultraviolet analytical apparatus (NDIR)		As in the case of NO measurement, NDIP method is possible but compared to the above mentioned FID method, it has the following demerits. Depending upon the type of hydrocarbon in the detector cell, the sensitivity differs. Hence it is very difficult to carry out the analysis of total hydrocarbons. NDIR method is specially meant for heavy hydro carbons and it is not possible to control at high temperature. In other words, if hydrocarbons having high boiling point are present, the condition becomes polluted by some of them. Hence FID is better to determine the total hydro carbon.	

4. Measures to reduce exhaust gas

Soot, smoke and oxides of nitrogen are considered to be the main components of the diesel exhaust gas causing pollution. The diesel smoke and soot may not have adverse effect on human beings but they cause unpleasant feeling and also hinder visibility. Moreover, the oxides of nitrogen react with hydrocarbons of air and in the presence of solar energy result in the formation of photochemical smog.

The method to decrease the harmful components of exhaust gas can be broadly divided into two categories, namely, an internal measure to control the formation of harmful components and an external measure to convert the harmful components into harmless components.

4.1. Measure to reduce the amount of soot and smoke(7)

The following methods are suggested to reduce the amount of soot and smoke:-

(1) Modification of combustion process ... mixture of air in right proportion, shape of combustion chamber, improvement in spray system.

(2) Complete equipment and maintenances of engine.

(3) Improvement of fuel... composition of fuel.

(4) Substances to prevent the formation of soot and smoke.. by using metal addition agents of barium system, the formation of smoke can be controlled. The effect on human beings, has not yet been confirmed.

(5) Fumigation... by spraying the fuel in the intake manifold, combustion can be accelerated.

(6) Dilution... air is blown in the exhaust pipe system.

(7) Engine derating... decreasing the maximum output.

(8) Filtered muffler.

4.2. Measures to reduce oxides of nitrogen(6, 8, 13)

The mechanism of NO_x formation was already discussed. The release of NO_x according to engine efficiency factor was studied and data so far collected suggest the following measures:

(1) Influence of the air combustion ratio.

In this experiment the consumption of air is so controlled that it becomes air combustion ratio in the combustion process. The maximum value of NO_x is found at air combustion ratio of 0.035 and the formation of NO_x decreases when the amount of fuel and air decreases. When an excessive amount of fuel is allowed to flow, the spraying of the excess part of the fuel is delayed in the combustion cycle. This causes a decrease in the temperature of heat degeneration and the formation of NO_x decreases as a result of delayed combustion.

Engine 4.5" I-C type single duct
Spray period BTC 11°
Temperature of absorbed air 40°F
Manifold pressure - 30" Hg abs.

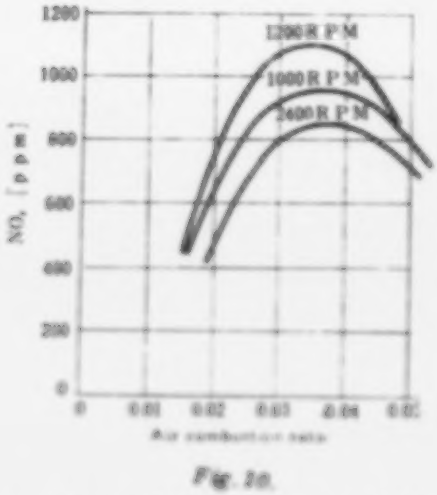


Fig. 10.

(2) Influence of fuel spraying period

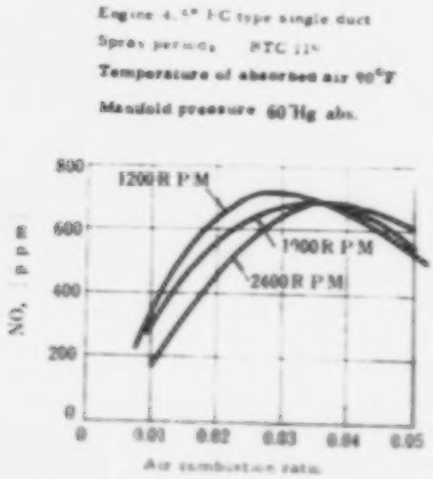


Fig. 11.

Fig. 4 shows the conditions of formation of NO_x when the spray period is changed with a constant amount of spray for one stroke. When the spraying rate is decreased, the formation of NO_x decreases. When the spray is rapid as in D, the absorbed air becomes cool by the evaporation of over-rich mixture and thermal degeneration increases. This brings about a decrease in the combustion temperature in localized regions and delays the combustion cycle. At the same time, the products of thermal degeneration increase and the smoke in the exhaust gas increases further.

(3) Influence of spray period

The fact that the formation of NO_x changes with the spraying period of fuel could be easily understood by studying the influence of the spray period on the condition of combustion. The influence varies according to the engine load and the engine speed.

(4) Influence of temperature of absorbed air.

The peak combustion temperature of diesel engine is related to the temperature of absorbed air. The chemical equilibrium constant for NO reaction increases with the rise in temperature. Hence, NO_x is formed at a higher rate when the temperature of absorbed air is high.

(5) Influence of negative pressure of absorbed air

When the negative pressure increases manifold, the spraying period is prolonged and the combustion cycle is delayed. As a result, the peak combustion temperature decreases resulting in the decrease in formation of NO_x.

NO_x is released in large amount when the combustion temperature is high and the oxygen is in excess. It is also affected by the continuity of combustion temperature. By suitably modifying these conditions it seems that the formation of NO_x can be controlled. The role of engine efficiency, the correlation among incompletely burnt products such as CO, HC, soot etc., are not easy problems from technical point of view. Hence, water injection method or exhaust gas recycling method to reduce NO_x release is being tried out as modifications of the engine, but the experiments have not yet shown encouraging results.

As a method to treat the liberated NO_x in an equipment outside the engine, the reduction of NO_x by using catalysts is being tried out. But the fact that the temperature for the effective use of catalyst is restricted as well as the fact that there are problems related to endurance have probably prevented this method from being applied to automobile engines.

5. Postscript

The present article describes mainly the mechanism of formation of soot and oxides of nitrogen in the diesel exhaust gas and the discussion is based on reports available in and outside Japan. While implementing the measures to control exhaust gas with a view to ensure clean air, it is necessary to confirm the method of measurement and also the analytical instruments and to evaluate with the same parameters.

The method to reduce NO_x is still under investigation and it will take sometime to make a final decision. There is no doubt that the automobile exhaust gas causes pollution of air and that it is necessary to find a preventive measure to remove the harmful components. However there are problems related to limited technique effective in reducing the amount of NO_x and also related to economy. By finding the exact relationship between the real nature of air pollution and the automobile exhaust gas, an objective to reduce the harmful components should be planned and it is necessary to carry out the measures on a long term plan.

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AIR POLLUTION AND ODOR

T. SAWAYA

Odor has become a great problem in recent times because of the sudden increase in its generating sources. The common man has realized that he should not sleep over the problem of unpleasant environment. At present, the administration in prefectures, cities and metropolitan areas have made regulations to control the pollution, and odor is included as a pollutant in the principal law.

1. Actual Stage of Pollution by Odor:

Of the various natural phenomena, although hydrogen sulfide coming out of hot springs is considered to be bad-smelling gas, yet the odor of this gas in the hot-spring places is harmless. In fact, the odor gives a favorable condition to the hot-spring air. But, when the hydrogen sulfide is given out by chemical industries, it becomes a public hazard in no time. The pollution is also due to some substances which pollute the drinking water and become detrimental to human body. The production of such substances accompanying the social life of human beings is the distinctive feature of public hazard. The odor from the industrial source causing pollution can be broadly divided into three types. That is,

Oil refinery: hydrocarbon, mercaptane etc.

Paper and pulp industry: organic sulfur compounds of mercaptane, terpenes.

Fisheries processing centers: amines, fatty acids etc.

Large factories emit mercaptane, hydrocarbons etc. in large quantities although in dilute form and these cause pollution by odor. But the regional dispersal of odor is mainly due to the animal growing and processing centers. The fisheries processing centers around the fishing belts have been known for a long time as odor emitting places. During the past 10 years the sources have increased by the formation of new centers like piggery, poultry and garbage burning centers.

1.1. Odor from pulp industry:

Mercaptanes are emitted from KP pulp industry and these have an unusual odor. Usually it is expressed as the same odor as that of decomposed cabbage. The main components of wood are ligunin and cellulose. Besides these, the wood includes a small quantity of resin. In the first step of manufacturing KP pulp, the wood chips are cooked at 170°C in chemical solutions (NaOH, Na_2S, NaHS). During the cooking, ligunin and resin dissolve but cellulose remains as the insoluble substance which will yield the pulp. Since ligunin and resin are dissolved in the cooking fluid, it becomes black-brown in color and is known as black fluid. The main sources of the odor are the blow tank which brings out the pulp from the cooking tank (wood vessel), black fluid condensing process, pulp washer and boiler. The components of odor are hydrogen sulfide resulting from the reaction of ligunin and sodium sulfide, mercaptane and alkyl sulfides.

H_2S is formed mainly by the hydrolysis of Na_2S, NaHS used in the chip cooking.

$$Na_2S + H_2O \rightleftharpoons NaHS + NaOH$$

$$NaHS + H_2O \rightleftharpoons NaOH + H_2S$$

It is believed that mercaptane, methyl sulfide etc. are formed due to the reaction of NaOH, NaHS with the ligunin which covers about half of the wood components ($LOCH_3$ is legunin).

$$LOCH_3 + NaOH = LONa + CH_3OH$$

$$CH_3OH + NaHS = NaOH + CH_3SH$$

$$LOCH_3 + NaSH = LONa + CH_3SH$$

$$CH_3SH + NaOH = CH_3SNa + H_2O$$

$$LOCH_3 + CH_3SNa = LONa + (CH_3)_2S$$

$$4CH_3SH + O_2 = 2CH_3SSCH_3 + 2H_2O$$

Besides these, ethyl mercaptane and diethyl sulfide etc. have also been detected as odor components. The actual values of these components are given in Tables 1 and 2. The odor limiting concentration of organic sulfur compounds is not always measured but it is believed to be 0.001-0.1 ppm. From the values of concentration of exhaust gases given in Tables 1 and 2 it is seen that the odor concentration rises sometimes even to a few thousand or in extreme cases 30-40 thousand. No wonder people in the locality where plans are made to build pulp factory protest against the idea.

TABLE 1

Sulfur oxides in KP pulp industry (Unit: mg/m^3)

	H_2S	CH_3SH	$(CH_3)_2S$	$(CH_3)_2S_2$
In the boiling flux of chip	800	4,600	5,900	8,300
From Pulp filtering machine	<1	1	240	2,700
Black fluid condensation exhaust	3,900	680	49	2,600
Storing of condensed black fluid	[illegible]	10	10	160
Chimney of collection boiler	[illegible]	10	7	120

(R. Cecerof, 196[illegible])

The path of smoke from the collecting boiler and the odor concentration of the gases from pulp washer as measured by the author are given in Table 3.

According to the measurement carried out by the Hygiene Research Center of Miyagi Prefecture, the odor components of KP pulp factory are found to be hydrogen sulfide, methyl mercaptane, dimethyl sulfide etc. The concentration of these components are said to have any value between a few hundreds to a few thousands ppm(2).

TABLE 2

Odorous substance of paper industry (Fuji City, Shizuoka Prefecture[1])

	H_2S concentration	CH_3SH concentration	$(CH_3)_2S$ concentration	$(CH_3)_2S_2$ concentration
Vapor blow tank Exhaust 30 m^3/minute	1.2 g/m^3	0.76 g/m^3	1.26 g/m^3	2.68 g/m^3
Pulp washer Exhaust 50 m^3/minute	1.0 mg/m^3	2.0 mg/m^3	0.6 g/m^3	1.02 g/m^3
Vacuum vapor	4.7 g/m^3	1.2 g/m^3	0.11 g/m^3	8.6 g/m^3
Lime combustion kiln Exhaust 200 m^3/minute	146 mg/m^3	0.1 g/m^3	64 mg/m^3	29 mg/m^3
Collection boiler Flue gas 200 m^3/minute	76 mg/m^3	30 mg/m^3	16 mg/m^3	280 mg/m^3

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[1] Japan Center of Environmental Hygiene. Measurements completed in September, 1968.

TABLE 3

Odor concentration in paper industry

Odor concentration	Method of measurement (factory, month and year)
Flue gas of the collection boiler, 50,000	Saline equilibrium method (Shirakawa City, Fukushima Prefecture, December 1969)
Exhaust from pulp washer, 10,000	

Taking the concentration of CH_3SH in the emission from the collecting boiler as 30 mg/m^3 (Table 2), the value when converted to volume ppm becomes about 14 ppm. However, if the odor limiting concentration of $(CH_3)_2S$ is assumed to be 0.0001 ppm, the odor concentration becomes 140,000. When the gas emitted from the chimney touches the ground because of downward wind, the gas concentration is usually diluted to about 100 times. In this case, the ground concentration of odor will become about 140. Besides the high level exhaust gas outlets like the boiler chimney, the low level outlets like the outlets of odor tank and lime furnace also form sources of bad odor. Hence the neighborhood of the factories have strong odor which gradually becomes faint. However, the odor once again becomes stronger in places considerably away from the factory. This is due to the odor emitted from high level emission outlets gradually descending in these places.

1.2. Odor from oil refinery:

Another major source of bad odor is the oil refinery. This is because of organic ion compounds and hydrogen sulfides formed during the desulfurization of crude oil. It is well known that mercaptans emitted from oil refinery in Kawasaki City during the summer of 1971 spread as far as the Western and Southern parts of Tokyo. Normally the odorous substances emitted from oil refinery include hydrocarbon, aldehydes, etc.

and all these leak out in minute quantities during the refining process. Measurement of these components are given in Table 4(1).

1.3. Odor from factories dealing with chemical synthesis

The sources of odor from fisheries processing factories are mainly protein and fats. Hence in this case also the odor results from multiple factors. Decomposition of proteins and fats occurs more or less in a manner shown in Fig. 1. The decomposition of natural protein and fat is accelerated by enzymes and bacteria at a particular humidity and temperature. Hence the odor from chemical synthesis factory and dairy storage is very strong during summer. The odor from fresh fish, birds and animals is very mild.

Again, if the type of raw material differs, the ratio of fatty acids and amines produced also differs. The amount of hydrogen sulfide and mercaptane are relatively poor. The main components of odor in the chemical synthesis factory are volatile fatty acids and amines. According to the results of measurement carried out by Hokkaido Hygienc Research Center, the concentration of odorous substance in the exhaust gas of drying process is as shown in Table 5(3).

Since amine, referred to in Table 5, has been calculated from nitrogen by using Kjeldahl's method, it can be represented by trimethyl amine. Fatty acids are represented by acetic acid, and mercaptane is represented by methyl mercaptane. Measurement of the composition of the individual group was not carried out. Odorous substances produced due to purification of proteins mentioned in Table 6 were detected by gas chromatography(4) and the IR absorption method(5).

The odor concentration in the chemical synthesis factory as measured by the author is given in Table 7. In factories where the odor is mild it is around 100 ~ 200 and in those where the odor is strong it may rise to 2000 - 3000. Recently, the author carried out a measurement of odor concentration in a poultry and a piggery centers. The results are given in Table 8.

TABLE 4

Gas leak from oil refinery

Place of measurement	i, n-butane	i, n-pentane	dimethyl butane	methyl cyclo-pentane	Acetone	Benzene
Within the plant building	0, 67 ppm	2, 3 ppm	0, 3 ppm	0, 07 ppm	0, 09 ppm	0, 09 ppm
At points of 100 m leeward	-	0, 5 ppm	0, 04 ppm	Mild	Mild	Mild

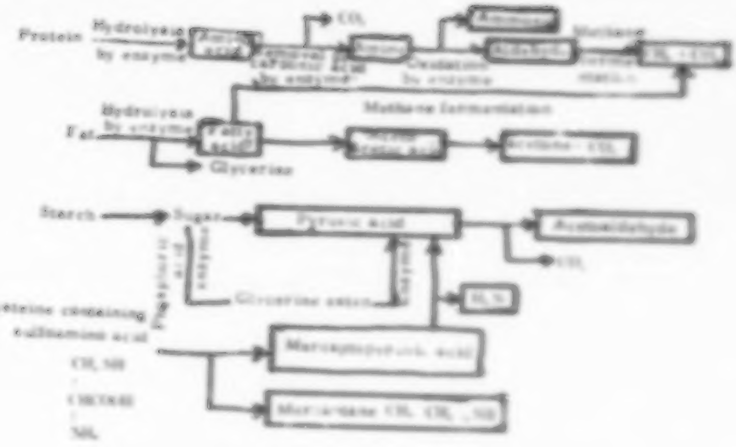

Protein
Hydrolysis by enzyme
Amino acid
CO2
Amine
Ammonia
Aldehyde
Oxidation by enzyme
Methane fermentation
Fat
Hydrolysis by enzyme
Fatty acid
Glycerine
Starch
Sugar
Pyruvic acid
Acetaldehyde
CO2
Glycerine ester
H2S
Cysteine containing sulfamino acid
Mercaptopyruvic acid
Mercaptane

Fig. 1. Course of decomposition of proteins.

2. Characteristics of odor:

The olfactory sense is one of the five important senses of human beings. Like the sense of taste, it too has not been scientifically explained. Hence, it is not possible to spell out the quality and strength of odor by a quantitative measuring instrument. The measurement of odor always depends upon the olfactory sense of human beings.

Sound waves affect the sense of hearing and light is felt by the sense of sight. In these, the number of oscillations of the waves determines the quality, and the strength is expressed by the amount (energy). Hence it is possible to express the relation by XY-graph and consequently it is possible to measure the strength and quality by an instrument.

The theory that "the olfactory organs of human-beings function by the irritation in the olfactory nerve in the nasal cavity by gaseous substance and minute particles" is not disputed. But the actual mechanism of this irritation is still not clearly understood.

Mercaptane is one of the representative substances emitting odor. The fact that the substances having a bond of -SH, -S- type possess odor was, for a long time, said to be due to the oscillation energy of the atom group of a part of the molecule causing irritation of the olfactory nerve. Hence, among the physicists

TABLE 5

Odor components in chemical factories

Process	Ammonia component (ppm)		Amine (ppm)		Fatty acids (ppm)		Mercaptane (ppm)		Hydrogen sulfide (ppm)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Fertilizer industry	19,7	1,5~ 47	13,4	0,37~ 38	8,2	7,6~ 8,9	1,3	0,82~ 1,95	0,94	0,18~ 2,1
Fodder industry	2,7	0,2~ 8,4	4,9	0,58~ 7,8	5,4	3,6~ 8,3	0,07	0,01~ 0,25	0,43	0,07~ 1,0
Fish cake industry (Dry exhaust)	5,0	0,7~ 29	4,3	0,43~ 17,8	6,7	0,71~ 16,9	0,13	0,007~ 0,64	0,43	0,06~ 1,53
Fish cake industry (Vapor Exhaust)	6,0	0,2~ 15	3,9	0,67~ 8,8	7,6	3,9~ 17,8	0,11	0,03~ 0,27	0,30	0,11~ 0,52

TABLE 6

Odorous substances produced due to decomposition of proteins

	Odor	Substance	Quality of odor	Odor limiting concentration	
Amines	Methyl amine	CH_3NH_2	Raw fish smell	0.021	ppm
	Trimethyl amine	$(CH_3)_2N$	"	0.00021	ppm
	Ethyl amine	$C_2H_5NH_2$	Smell of ammonia	-	
	Diethyl amine	$(C_2H_5)_2NH$	"	-	
	Triethyl amine	$(C_2H_5)_3N$	Decomposed fish smell	-	
	Pyridine	C_5H_5N	Unpleasant smell	0.23	ppm
	Ammonia	NH_3	Irritating smell	55	ppm
Sulfides	Ethyl mercaptane	C_2H_5SH	Garlic smell	0.00026	ppm
	Dimethylthioether	CH_3SCH_3	Scallion smell	0.01	ppm
	Hydrogen sulfide	H_2S	Decomposed egg smell	0.13	ppm
Fatty acids	Acetic acid	CH_3COOH	Irritating smell	2.6	ppm
	Propionic acid	C_2H_5COOH	Unpleasant smell	0.015	ppm
	Formic acid	C_3H_7COOH	Sweat smell	0.00056	ppm
Ketone-aldehyde	Acetone	CH_3COCH_3	Urine smell	1.6	ppm
	Acetoaldyhyde	CH_3CHO	Irritating smell	0.066	ppm
	Propionaldehyde	C_2H_5CHO	Irritating smell	1.0	ppm

TABLE 7

Odor concentration of exhaust emitted from tubes in chemical factories (saline equilibrium method)

No.	Factory (name of the product)	Samples and the places from where these were collected	Odor concentration	Date of measurement	Remarks
1	2	3	4	5	6
1	**Ishimaki-Shi, M. Company** **{Absorbed fodder, Fish meal, Fish soluble}**	**Absorbed fodder, Exhaust tube of rotary drier**	100	**August 1965**	**Odor around the factory is very mild.** **Temperature at the exhaust tube outlet (2 meter above the ceiling) is 100°C.** **Odor removing equipment is not provided.** **As the odor collecting jar was kept above the ground, the condensing water in the vinyl tube was left and the odor concentration was somehow reduced.**
2	Ishimaki-Shi, T. product (absorbed fodder)	Absorbed fodder, Exhaust tube of drier	3,000	**September 1965**	**Odor around the factory is mild.** Sparsely-populated. Temperature at the exhaust tube outlet (5 meter above the ceiling) is 100-110°C. Odor removing equipment is not provided. pH of collected fluid = 4.2.

1	2	3	4	5	6
3	Shiokama-Shi, M. Company	Fish-soluble, Exhaust tube outlet after odor removal of the condensed fish soluble	650	September 1965	Odor around the factory is mild. Six of the fish-soluble condensing tanks were closed tightly. After removing odor from the exhaust with two – stages condenser. it was passed through a tube at about 3 meter above the ceiling. pH of collected fluid = 10.5
4	Shiokama-Shi, N. Fisheries (Fish soluble flakes)	Exhaust tube right above the odor removing water tank	170	September 1965	Odor around the factory is mild. The waste is made to pass through a multitude odor removing equipment with the help of a duct (30 cm ϕ, 15 m inside the ceiling and 10 meter above the ceiling). It then enters water storage tank (tightly closed) kept underground. From the storage tank, it is then released through a separate pipe (10 m high). pH of collected fluid = 4.4 pH of water in the water tank = 7.6
5	Kesennuma-Shi, K. Company (dry fertilizer)	Exhaust pipe of rotary drier	620	September, 1965	Sparsely populated. The exhaust gas scatters to a far-off distance (about 2 km) in the form of white smoke. It has strong odor. Exhaust pipe is 3 m above the ceiling. Temperature of the exhaust is 80°C. Odor removing equipment is not provided. pH of collected fluid = 8.9

1	2	3	4	5	6
6	Kesennuma-Shi, K. Company (Fish-soluble, Fish meal)	Exhaust pipe of rotary drier	2,000	September, 1965	Odor around the factory is mild. Exhaust pipe is about 5 m above the ceiling. Temperature of the exhaust is about 50°C. Odor removing equipment is not provided. pH of collected fluid = 6, 8
7	Kesennuma-Shi, I. Fisheries (Fish meal)	Exhaust pipe of rotary drier	1,600	September, 1965	Odor around the factory is mild. Exhaust pipe is 43 m above the ceiling. Temperature of the exhaust is 60°C. Odor removing equipment is not provided. pH of collected fluid = 4, 0
8	Kesennuma-Shi, H. Company (Fish meal)	Exhaust gas after washing of the waste from rotary drier in a coke-packed tower	200	September, 1965	Odor around the factory is mild. It is made to pass through coke tower of size 80 cmφ×4 m. Temperature of the exhaust is 20-25°C. pH of collected fluid = 5, 6
9	Iwaki-Shi, S. Shop	Fish meal, Exhaust from the drier (after it has been passed through odor-removed tower)	2,500	December, 1969	pH of the absorbed fluid = 3, 0, Total fatty acids = 5,7 epm Total amines = 1,7 epm

TABLE 8

Odor concentration in poultry farm and piggery farm (Saline equilibrium method)

	pH of absorbed fluid	Odor concentration	Date of measurement	Remarks
Iwaki-Shi, J. Stock-breeding, Drying of chicken manure	6.7	84	December, 1969	Measured at the exhaust outlet for drying of chicken manure. Odor removing agent is used. Total fatty acids in the absorbed fluid = 3.1 epm. Amines = 2.6 epm
Soma-Shi, H. Piggery Farm	6.0	26	December, 1969	Measured inside pigsty
Namse, Fukoshima Prefecture, T. Piggery Farm	6.0	51	December, 1969	Measured inside pigsty
O-Poultry Farm	8.5	200	December, 1969	Measurement of waste after drying of chicken manure. Exhaust release in the earth.

there was a belief that the human-beings receive the odor at a particular wave length range in the distant infrared region. However, till now this has not been proved.

The following is a brief account of the data collected for olfactory receptor.

2.1. Types of odor and odor strength:

According to the molecular oscillation theory, the types of odor correspond to the specific spectra in a particular wave length range. Although, a general expression is used it shows a wide range of errors. Examples which can be used conveniently in the types of odor from industrial sewage are given in Table 9(b).

Besides these, there are various types of odor derived from drugs, tar, metals, excreta etc.

The odor strength is also difficult to be expressed in the form of numerical values. Although it looks highly generalized, this can be divided broadly into the following 5 stages.

2.2. Olfactory sense:

Olfactory sense is very delicate and there is much difference due to psychological and physiological factors. However, a general principle applicable to the majority is described below:

(a) Weber-Fechner Rule:

When a very strong smelling gas is present, the odor strength does not vary much even by diluting the gas to 2 or 3 times. When the same is diluted to 8 or 10 times the odor strength reduces to about half of the original. By studying this fact in the light of the 5-stage classification method of the strength given in Table 10, the numerical formula becomes as follows. This is known as Weber-Fechner Rule.

$$S = aC^n$$

$$I = \log S = \log a + n \log C$$

S = Amount of odor sensitivity
C = Gas concentration
a = Proportional constant
n = Constant derived from the type of gas
I = Odor strength (according to 5-stage classification method).

This rule when explained in words becomes:- even when the gas concentration doubles, the odor strength usually does not increase to 2 times and the odor strength is proportional to n-power of gas strength.

Kerka et al. studied the applicability of Weber-Fechner Rule for various types of odorous gas. Results for 4 types of gases are shown in Table 2(7).

TABLE 9

Qualitative classification of odor

Symbol	Meaning
a	Aromatic
c	Free chlorine
d	disagreeable
e	earthy
f	fishy
g	grassy
m	moldy
M	musty
p	peaty
s	sweetish
S	free H_2S
v	vegetable

TABLE 10

Classification of odor strength

0	Odorless
1	Very mild odor
2	Distinct odor
3	Strong odor
4	Unbearable strong odor

According to Fig. 2, the 4 straight lines are more or less parallel (there are problems in drawing up the straight lines). Hence, it is understood that n for these 4 substances is the same. Gas strength at the vicinity of 0.5 of odor strength is the minimum concentration at which the odor of the gas can be felt. This minimum concentration differs according to the type of odorous gas. Among these 4-types, n-acetic acid has the strongest odor and 0.001 mg/m^2 is the odor limiting concentration.

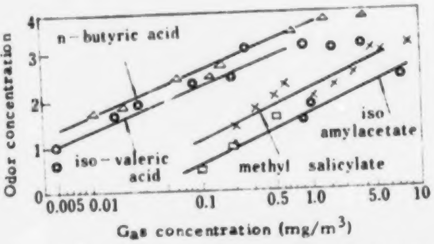


Fig. 2. Relationship between odor strength and gas concentration.

(b) Acclamatization (Weakening):

Although the pulp factory emits a very peculiar odor, people who are working in the factory are said to be almost uneffected by the odor. This is what is known as acclamatization to odor (fatigue of olfactory sense). This is often felt even in daily life. Usually if a person is smelling an odorous gas for more than 5 minutes, either he gets acclamatized to the odor or it becomes unbearable. It is necessary to be careful in this point while measuring the odor strength.

(c) Individual difference:

Like blind and deaf people, there are also persons who do not have the power of olfactory sense. On the other hand, there are people who are extremely sensitive to odor. They are often called dog-nosed. There are also cases where the same odor which is liked by some but is disliked by others. However, it is possible to have a more or less general type of olfactory sense from the majority of persons examined. Regarding the measurement of odor strength, persons who are extremely dull or extremely sensitive to odor should not be taken into consideration.

(d) Complex odor in which more than 2 substances are mixed:

When a small quantity of sugar is added to milk, the sweet taste can be strongly felt. However, when sugar is added to green tea, as compared to the single taste of sugared hot water, the sweet taste is lost to a great extent. The same can be said about odor also and there are cases in which the effect of adding is not manifested. A chemical reaction occurs when 2 types of gases are mixed and when a 3rd substance is produced it results in complex odor. The weakening of odor in the absence of chemical reaction can be applied for deodorization.

2. 3. Types of odorous gases and their odor strength

Substances emitting odor may be solids, liquids or gases. However, the odor can be sensed only when the substance is volatile and is either gas or aerosole.

Much is known about pure substances emitting filthy(8) odor.

One of the methods to measure the odor strength of odorous gas is to express in terms of gas strength when the odor strength at a known level is 0.5. This strength is said to be the threshold concentration or limiting concentration. At this strength, a large number of people can recognize the odor. For example, ammonia cannot be smelt by people when its concentration in air is below 55 ppm but the odor of hydrogen sulfide can be felt even if it is 0.13 ppm. Regarding the odor threshold concentration of pure substances, there is a detailed description by Stern(8) and others(11). Hence only a few points are referred to here in Table 11.

TABLE 11

Odor strength in odorous gas

Materials	Threshold concentration	Molar olfacty
Ammonia	55 ppm	1.8×10^4
Sulfurous acid gas	3.1 ppm	3.2×10^5
Chlorine	3 ppm	3.3×10^5
Carbon disulfide	0.8 ppm	1.2×10^6
Pyridine	0.23 ppm	4.3×10^6
Hydrogen sulfide	0.13 ppm	7.7×10^6
Ozone	0.015 ppm	6.7×10^7
Ethyl mercaptane	0.00026 ppm	3.8×10^9
Thiophenol	0.00026 ppm	3.8×10^9
Synthetic musk	0.000075 ppm	1.3×10^{13}

The odor strength increases with the decrease in the threshold concentration of a substance. Thus if it is convenient to use the expression that the value for strong smelling substance is large it is also convenient to use molar olfacty. Hence molar olfacty can be said as odor concentration of pure gas at 1 atm. (at normal temperature). It is equal to the molar absorption of light in the case of photo-absorption of a solution.

Although the correct value of the concentration of a single substance in the odorous gases of chemical industries is not known, it is possible to know through the odor whether or not there is a threshold concentration.

Beside the odor concentration there are various other factors involved in the gas concentration method. The following is a brief note on the common units used in the method:

Volume ppm: ml of gas present in 1 m^3 air

$mg/l = oz/1000\ ft^3 = g/m^3$

Conversion to vol. ppm → mg/m^3

$$ppm \times \frac{M}{22.4} = mg/m^3$$

(here m is the molecular weight of gas)

$$\text{Molar olfacty} = \frac{10^6}{\text{(threshold concentration)}}$$

The problem now is whether or not the substances emitting odor are poisonous. While it is alright to call them poisonous substances, it is not correct to say that substances emitting odor are more poisonous than substances emitting weak odor. For example, if a comparison is made between the carbon disulfide and chlorine, it is found that chlorine is more poisonous although the odor of carbon disulfide is stronger.

	Odor limiting concentration	Permissible concentration ensuring the health of laborers
CS_2	0.8 ppm	20 ppm
Cl_2	3 ppm	1 ppm

Even odorless substances like carbon monoxide can be highly poisonous. Hence, the assumption that the odor of the poisonous gas is naturally removed, is not applicable to all gases.

Most of the odor which causes pollution is from a mixture of several gases rather than from a single gas. Although it may be assumed that bad odor is not a potential hazard, yet logically it seems to be a public hazard.

3. Method of measurement of odor:

Regarding the measurement of any odor, there are two steps, namely, the quantitative estimation of odor of the components and the measurement of odor strength. As a method to measure the odor of components, at present, gas chromatography is widely used(9). Usually, the odor of the gas components present in the atmosphere is measured not straightaway subjecting to gas chromatography, but after the condensation of these components.

In order to measure the odor strength, a very simple apparatus is used and the measurement depends upon the sense of smelling. This method has been in use for a long time and no improvement or modification has been made so far. Even if the anatomical mechanism of the olfactry sense is explained in detail, the quantum of olfacty stimulation cannot be set in the form of numerical values. This is the reason why a measuring instrument for odor strength has not been developed.

The types and concentration of color and the types and strength of sound can be classified by the intensity of waves and the number of vibrations. However, the olfactory and gustatory senses cannot be analyzed by qualitative or quantitative analysis of the spectrum and strength. Regarding the quality of odor, there is a molecular vibration hypothesis which however has not been sufficiently proved.

Regarding the measurement of odor strength of gases, there are three methods, viz. A. S. T. M. method(10), method suggested by Dr. Terabe(11), and a simple method by the author(12). The following is a brief account of these methods.

3.1. Air dilution method:

Odorous gas is diluted in a non-odorous gas and the dilution ratio when the odor strength becomes 0.5 is called the odor concentration. There are some problems in the diluting apparatus and the materials of the apparatus. Besides, a number of precautions are required while collecting the samples for olfactory experiments. Hydrogen sulfide gas oxidizes in air whereby the concentration rapidly decreases. Odorous gases are adsorbed by vinyl tubes and polyethylene bottles. Rubber materials are not suited for the olfactory experiments.

In fact, the air dilution method in principle is the best method and will be the ideal method if the problems related to materials used and the apparatus are solved.

3.2. Saline equilibrium method(12):

The components of odorous gases emitted by inorganic and synthetic chemicals industries are mostly simple substances but those of gases emitted by the manufacturing industries which made use of natural substances as raw materials are often a mixture of several components. In order to define odor, it is necessary to measure the composition of these mixed gases, but to study the composition in relation to public hazard, the measurement of odor strength also poses a problem. Although the main components of mixed gases and their concentration can be determined, yet the odor strength does not always agree with these factors. This is because there are several problems such as the difference in the reciprocal action of mixed gases and resisting action, which differ according to the odor limiting concentration of the gases.

Earlier, the author had discussed method of measurement of odor concentration including the sampling of bad-smelling gases. The author also studied a number of theoretical factors involved in this method. The principle of sampling is shown in Fig. 3.

The sampling bottle consists of impinger, gas absorbing tube and gas washing bottle. A suitable vacuum pump can be used as suction pump. The amount of suction is so adjusted that the saline water in the sampling bottle does not evaporate.

In the sampling of gases, usually the measurement of suction is also simultaneously carried out, but recently there is

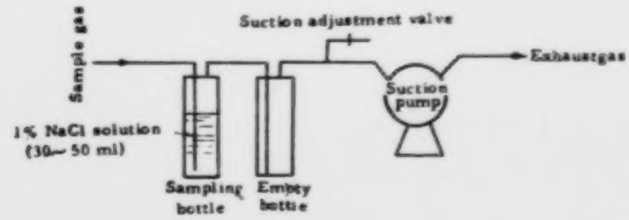

Sample gas
Suction adjustment valve
Exhaustgas
Suction pump
1% NaCl solution
(30~50 ml)
Sampling bottle
Empty bottle

Fig. 3

a method in which this is not done. The amount of suction can be converted into suction time. The duration of suction varies according to the gas absorption capacity in the sampling bottle, but if the sampling bottle can be made in a fixed shape, the amount of suction can be converted into suction time. Let us consider a model shown in Fig. 4 with the following assumptions:

p: Partial pressure of odorous gas present in the sample.
p': Partial pressure of gas coming out of the absorption tube.
V: Amount of absorption fluid (ml)
v: Amount of gas sucked (l)
t: Suction time of gas

C: Concentration of gas in the absorption fluid.
C^*: Concentration of gas in the absorption fluid when p becomes equal to p'.

Under the above-mentioned conditions, p becomes equal to p' after a suitable suction time. Theoretically speaking, in order to make $p = p'$ an indefinite period is required but order to make $p' = 0.95\text{-}0.99p$, the time is limited. If this apparatus is taken as the sampling bottle, and instead of carrying the sample gas in the

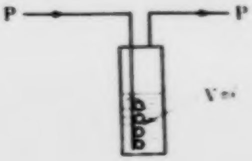


Fig. 4

form of gas into the experimental laboratory if the measurement of odor strength of p' is carried out by carrying the absorption fluid into which the air is blown in, it will tally with the odor strength of most of the samples. The relationship involved in this can be explained by the following equation:

$$2.303 \log \frac{C^*}{C^* - C} = \frac{K_L A}{V} t = \frac{K_L A}{V} v \qquad (1)$$

K_L : Coefficient of transfer of matter (it expresses the movement of gas through the boundary between air bubble and liquid)
A : surface area of air bubble.

Since C^* is concentration of gas in the absorption fluid when $p = p'$, this is called the equilibrium concentration. In fact, even if p' is not exactly equal to p but has the relationship $p' = 0.95 - 0.99\ p$, it can be considered as a suitable sampling.

The results of the experiments carried out by the author are given in Table 12.

The results showed that by using a particular type of absorption apparatus if the speed of gas permeability is kept constant, it is possible to obtain an almost constant value of $K_L A$ irrespective of the amount of gas passed. Theoretically, the value of K_L changes according to the type of gas but practically speaking there is not much difference. Since A represents the surface area of air bubble, if the air bubbles are minute, it should be possible to shorten the suction time (amount of gas passed) but in the case of gas absorption tube of commercial variety, there is not so much difference. Results of the experiments in which the tube had globular glass particles are given in Table 12.

$K_L A$ did not differ much from the values given in Table 12, and the values obtained were slightly smaller.

In the case of actual sampling the suction time should be shortened to the minimum and for doing this it is necessary to increase the amount of gas flow without any evaporation of gas-liquid. It is also effective to minimize the amount of liquid absorption.

TABLE 12

Sample - mild CH_3NH_2 gas, Absorption bottle - muenk-type, gas washing bottle (250 ml capacity)

P (%)	V (mg)	t (min.)	v (l)	C* (mol/l)	C (mol/l)	K_LA	$\frac{K_LA}{V}$
0.53	150	60	60	0.720	0.0765	0.318	
0.51	150	40	40	0.663	0.0495	0.298	1.95×10^{-3}
0.51	150	80	81	0.699	0.0975	0.281	
(1% saline solution)							
0.51	150	60	60	0.684	0.0731	0.281	
						Mean 0.293± 0.025	

Although there are different types of apparatus for sampling, the author preferred a simple apparatus shown in Fig. 4. In an apparatus of this size, only 30-50 ml of fluid is required and it is also possible to considerably accelerate the rate of air passage. Moreover, the suction time can be reduced to 1.5-2 hours.

Instead of distilled water it is better to use 1% saline solution as the absorption fluid. This will ensure a stable condition when the odorous gas is absorbed by water and substances like amines and fatty acids are ionized. Again, since the solubility of gas in saline solution is smaller than in water, the equilibrium in the absorption fluid is attained rapidly.

For carrying out olfaction experiments the absorption fluid of odorous gas can be conveniently carried into the experimental laboratory in an apparatus shown in Fig. 6.

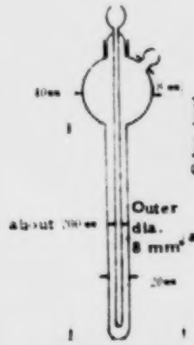


Fig. 5

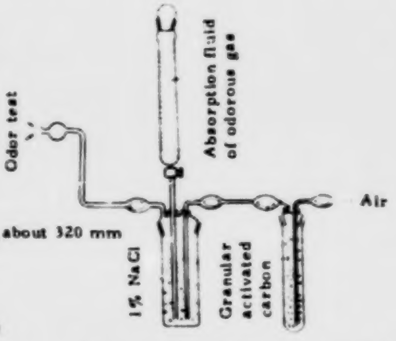


Fig. 6. Odor testing apparatus.

Details of the trimouth cylinder and burrettes are shown in Fig. 7.

When odorless air is passed through a fluid which has attained solubility equilibrium the concentration of gas is more or less the same as of the gas sample. The concentration of gas produced by the absorption fluid is proportional to the concentration of the gas dissolved and this can be expressed by the following equation.

$$p' = HC \qquad (2)$$

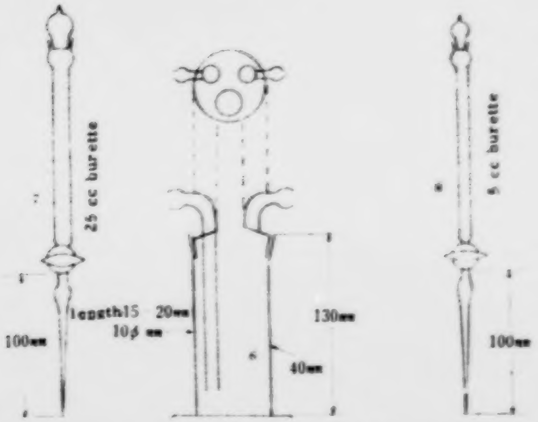


Fig. 7. Odor measuring apparatus.

The symbols used here are the same as in the equation (1). H is the Henry constant determined on the basis of the type of gas and temperature. While applying Henry's rule the gas collecting fluid added in drops to 1% saline solution (Fig. 6) is diluted and concentration of gas produced by the diluted fluid is the same as the concentration of the sample gas when diluted with odorless air. Hence it is sufficient to add the odor collecting fluid in drops till the odor limiting concentration is attained. The dilution ratio of the fluid corresponds to that of the odorous gas by adding air. Henry's rule is not applicable to gas with very high solubility and gases that react chemically in water. However, if some correction is made in the value of C of equation (2), Henry's rule can be applied. For example, in the case of absorbed gas in which a part of it shows ionization of amines and fatty acids, the concentration of the part which does not show ionization can be taken into consideration. If C is the sum of ionized part and the part which does not show electrolytic dissociation, the adjusted value α_0 should be multiplied by C. Equation (2) becomes as follows

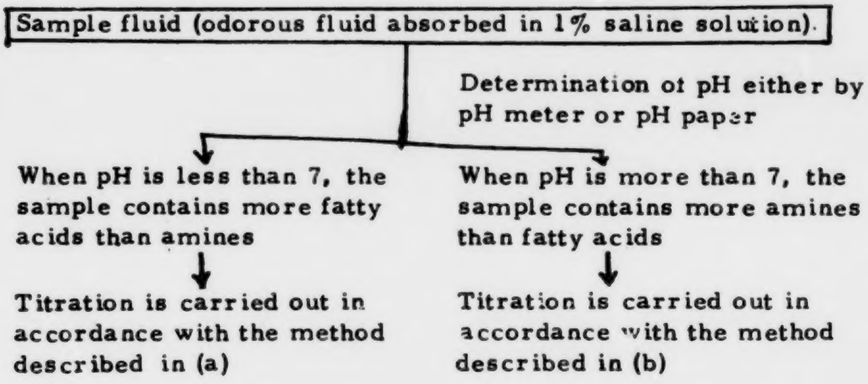
$$p' = HC\alpha_0 \tag{3}$$

$$\alpha_0 = \frac{\text{Concentration of non electrolized part}}{\text{(concentration of the part without electrolytic dissociation)} + \text{(concentration of ionized part)}} \tag{4}$$

Since in the case of odorous gas having strong electrolytic substances (HCl gas, NH_3 gas etc.), $\alpha_0 < 1$, it is probably necessary to make the sampling where the amount of air passed will be slightly more than that of non-electrolytic gas.

3.3. Method of measurement of total amount of odorous substances in chemical processing factories

As already mentioned, the odor emitted by fisheries processing factory, slaughter houses, and cattle breeding places, has the decomposed part of protein (amines and fatty acids) as the main component. The contents can be measured by gas chromatography but the total amount of fatty acids and amines can be measured by titration. In this case, all the fatty acids are calculated by converting into acetic acid (in case it cannot be determined as acetic acid it can be taken as butyric acid). All the amines are expressed by converting into methyl amine. The method of measurement is as follows:



Sample fluid (odorous fluid absorbed in 1% saline solution).

Determination of pH either by pH meter or pH paper

When pH is less than 7, the sample contains more fatty acids than amines

Titration is carried out in accordance with the method described in (a)

When pH is more than 7, the sample contains more amines than fatty acids

Titration is carried out in accordance with the method described in (b)

(a) When pH is less than 7

When the total amount of absorbed fluid is expressed as V_{ml}, a fixed amount of V_{ml} is taken from it and using phenolphthalein as indicator the solution is titrated till it shows a light orange color with NaOH standard solution (0.02-0.1N), that is, ($pH = 8.5$). The titrated amount is taken as A ml. Since the color disappears by adding 5-10 ml of 20% formalin solution, the titration is continued till the appearance of a light orange color. This amount of titration is calculated as B ml. At the same time, a blank test is also carried out by using 1% saline solution. If the total amount of standard fluid is taken as A ml, the amount of CH_3COOH in the absorbed sample is calculated in the following way:

$$\text{Amount of } CH_3CCOH \text{ (mg)} = 60N \times (A+B-a) \times \frac{V}{v}$$

(N is the concentration of NaOH standard solution). The amount of CH_3NH_2 in absorbed sample is calculated in the following way:

$$\text{Amount of } CH_3NH_2 \text{(mg)} = 31N \times (B-a) \times \frac{V}{v}$$

(b) When pH is more than 7

When the total amount of absorbed sample solution is taken as Vml, a fixed amount v ml is taken from this and using bromthymol blue as indicator, titration is carried out with HCl standard solution (0.02-0.1N) till it shows yellow color ($pH = 6.0$). The titrated amount is taken as C ml. Another titration is carried out separately by taking v ml of the sample fluid to which 5-10 ml of 20% formalin solution is added. After adding phenolphthalein indicator, the titration is continued with NaCH standard solution till the solution shows light orange color. The amount of titration is taken as D ml. Again, v ml of 1% saline solution is taken and after adding formalin a blank test is carried out with NaOH standard solution and the amount is taken as d ml. The calculation of total fatty acids and amines is carried out in the following manner:-

$$\text{Amount of } CH_3COOH \text{ (mg)} = 60N \text{ (D-d)} \times \frac{V}{v}$$

$$\text{Amount of } CH_3NH_2 \text{(mg)} = 31 \text{ FC} \times \frac{V}{v}$$

(F is the concentration of HCl standard solution).

4. Measures to check odor:

In principle, the method of checking odorous gas (simple) emitted by chemical processing industries is comparatively simpler. Gases produced by the purification of animal and plant substances are extremely unpleasant and the gas components are complicated. A principle to check such odor has already been evolved. The problem now is to select a suitable method on the basis of economic, technical aspect and applicability to a particular factory. Although an equipment to check the odor may be installed, the effect may not always be striking. Some of the reasons are:

Improper designing of the equipment;
Unsuitability of operational method;
Special characteristics of olfactory sense.

The effect will be very good if 90-95% of ordinary gas and particulates can be removed according to Weber-Fechner rule. However, even if the odor concentration is reduced by 90-95%, the remaining 5% can still emit strong odor. Even 99% removal can leave behind a strong odor from the remaining 1%. Hence, while checking the odor, the real effect can be attained only when 99.9-99.99% is removed. Thus, it is necessary to devise an odor removing equipment by which the odor can be removed not in one step but through several steps.

The following is the classification of odor removing method

Physical methods		Washing-spraying method; method in which air is passed into water; cooling-condensation method Adsorption method-active carbon method; air dilution method
Chemical method	Chemical treatment method	Acid, alkali washing method; Chlorine treatment method; Ozone treatment method; Suppression method
	Combustion method	Repeated combustion method; and Catalytic oxidization method

4.1. Washing method:

This is the simplest method when there is no problem in the supply and draining of water for washing. Even sea water can be used for washing. But, it is necessary to collect the odor effectively. When fish soluble is concentrated from the juices obtained from fishes in an open vessel, the odor emitted is very unpleasant. But if a vacuum concentration is carried out, the odor is considerably mild. This shows the effect of washing (in water) method. When non-condensing gas such as air is included, washing method, spraying method, air passing method can be effectively used.

4.2. Condensation method:

This is effective when the gas emitting foul smell is at a high temperature and the amount of water vapor contained is high. It is suitable for removing the odor from the gas coming out as concentrated vapor from the treating substance. It is better to design the equipment in a manner in which the condensed exhaust gas comes out at low temperature (about that of the atmosphere) and the cooling effect is also better.

4.3. Adsorption method:

In this case active carbon is commonly used. The problem here is the high cost of active carbon. Moreover, since the odor is removed by re-production, the maintenance and management of the method should be carefully considered. If active carbon is available at a cheaper rate, it can be used as fuel without considering the re-production. However, as the use of re-production is common at present it will become a problem in the medium and small enterprises.

4.4. Air dilution method:

Even odorous gas becomes harmless when it is diluted in odorless air below the limiting concentration. However, as explained earlier, in order to dilute the odor from exhaust tower of factories to odorless gas, it has to be diluted 100-1000 times in air. At present it is almost impossible to attain this dilution. Air dilution method can be carried out to about 10-20 times

There are factories where sulfurous acid gas of low concentration is diluted to about 10 times while draining out. But there is no factory where the dilution method is carried out to lower the odor concentration.

4. 5. Acid-alkali treatment method and ion-exchange method:

It is very difficult to completely remove the odor by washing and even a 90% removal can be called a major achievement. Instead of water if acid or alkali is used for washing, the odor can be removed more effectively Majority of odorous gas is believed to be either acidic or alkaline substance. In that case, it is sufficient to use sulfuric acid or soda ash. The problem, however, in this case, is the materials of the apparatus used for acid treatment. Moreover, acid-alkali is consumed at a constant rate and besides it involves draining of fluid waste. If this type of odor removing apparatus is installed in medium and small enterprises where the number of workers is small, there will be the problem of maintenance and management of the equipment. Although the method is simply known as the odor removing method, it is actually the active carbon adsorption after acid-alkali treatment. Besides being very costly, the maintenance of equipment will incur several other expenses. Hence the method cannot be considered immediately.

Recently, as odor removing agent in poultry farm, the spraying of a mixture of a particular type of acid salts and basic salts (both of these are obtained as waste products from factories) has been reported to be an effective method.

An ion-exchange method is another method for checking odor. In order to minimize the resistance against the passage of gas in a tower, it is necessary to use coarse ion-exchange resin. Moreover, it is necessary to use acid-alkali in the re-production of resin. When re-production of acid-alkali is not carried out, it can be replaced by saline water. In any case it has the disadvantage of involving several steps for maintenance and management.

4.6. Chlorine and ozone treatment method:

The question now is whether it is possible to remove the odor produced as a result of decomposition of animal and plant materials by applying chlorine treatment. At present, there is no evidence from experiments. Although the effect is believed to be seen in the removal of odor from hydrogen sulfide and mercaptanes, the same effect cannot be expected in the case of volatile fatty acids. On the other hand, chlorine gas is a bad corrosive for metals and hence one has to be very careful about the materials used in the equipment.

Ozone treatment is also believed to have the same effect in removing the odor as in the case of chlorine treatment. It is effective in the case of organic compounds with double bonds. Besides, it reacts rapidly on sulfates, amines, aldehydes etc. When using ozone as an odor removing agent it is necessary to study the relationship between the amount of ozone supply and the amount of odorous gas and then design the equipment. It is very difficult to find out a processing factory where ozone is used.for the removal of odor. However, it is certain that the ozone producing equipment capable to cope up with removal of enormous odor will have to be very large. According to a report the effect of applying the ozone method on an experimental basis was not encouraging. It is believed that it is effective when the odor concentration is not very high.

Ozone treatment is simple as far as the electrical and mechanical operations are concerned and there is no chemical residue which otherwise becomes a problem. However, further reports are awaited for a detailed study on the application of this method.

4.7. Suppression method:

When an odorous substance reacts with chemicals, it is but natural that the odor disappears as a result of the formation of a different substance. This is not a chemical action but a method by which the olfactory sense is changed physically. At present, it is not known for certain what exactly is effective for a particular type of odor. There are some experimental examples. At Hakodate, vanillin was added to pounded shellfish at the rate of 1-3

TABLE 13

Odor removal rate by various methods

Odor removal method	Samples	Odor concentration		Remarks
		Before treatment	After treatment	
Ozone treatment water washing	Fish soluble, Waste after drying of absorption fodder	1,100	650(42%)	Ozone concentration: 28.5 ppm Quantity of water used for washing - 20 l/minute (47 l/m^3 sample)
Vinilon fiber tower: water absorption method	-do-	840	630(25%)	Amount of gas used for treatment - 6 m^3/min.
				Amount of water used for washing: upper stage 11.6 l/min., lower stage 27.3 l/min, 6.5 l/m^3 sample
Anion exchange tower: water absorption method	-do-	1,000 500	1000(0%) 500(0%)	Anion exchange: Meta-phenylene diamine polymer "pricot"
	Vapor during cooking	30,000	1300(95%)	Pricot amount: 20 l
	Dry exhaust	1,000	300(70%)	Amount of gas used for treatment: 16 l/sec.
Sulfide tower: water absorption method	Vapor during cooking		420(20%)	Amount of gas used for treatment: 1.15 m^3/min.
	Absorbed fodder waste		1100(34%)	Amount of water used for washing: 9.5 l/min, 8.25 l/m^3 samples
Acid, alkali washing method	Dried Fish meal		NH_3 removal rate 98-99%	Sulfuric acid washing tank: 2% H_2SO_4 3m^3 (2x1.5x1 m)
				Caustic soda washing tank: 10% NaOH 10m^3 (2x5x 1m)
				Amount of gas used for treatment: 60 m^3/min.
Continued washing and absorption method	Dried absorption fodder		Odor removal rate 90%	Amount of water used for circulation: 7-14 m^3/hr. Amount of gas used for treatment: 110 m^3/min. This instrument yielded good results at times.

parts to 10,000 and then dried, the odor became almost nil. As this is still in the experimental stage, further details are awaited.

4.8. Recombustion method:

Odorous gas has low moisture content and when the gas contains a considerable amount of air, it can be combusted by mixing with air supplied in a boiler. There is also another method in which odorous exhaust gas of rotary drier is emitted after passing through a high temperature burning part. It is said that odorous gas breaks up at high temperature such as 700°C. Since combustion is always not required at a high temperature treatment like this, it is not necessary to pass air.

4.9. Catalytic combustion method:

The principle of this method is very old and it is now used in the removal of exhaust air in factories by combustion. It is very common in lacquer paint factories and plastic paint factories where the solvent is removed after combustion. Since all the odorous organic gases can be combusted, when a metal net with platinum catalyst is passed, the gas is made odorless by catalytic combustion. However, there is no factory where this has been used to remove the odor. Experimental results have been reported by Dr. Ishikawa. In this method, the temperature of platinum catalyst has to be maintained at 350°C and the presence of excess air is necessary. Moreover, a condition in which particulates should not be present in the gas in which the metal net is passed is also necessary. When these conditions are satisfactory, treatment of odorous gas is effective.

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REFERENCE LITERATURE RELATED TO CHECKING OF AIR POLLUTION IN ROOMS (SUSPENDED PARTICULATES) FOUND IN THE STUDY OF ARCHITECTURE (I)

1955-1967

F. SUGAWARA

Air inside the room becomes polluted due to the particulates and bacteria in the air and it is well-known that due to these factors the building becomes dirty which again results in affecting the people living in the buildings. It would be possible to improve the living conditions in a room by studying the relationship between the building materials and the degree of cleanliness of air in the rooms. While studying the recurrence due to the activity and working of persons living in the room, diffusion from outside, precipitation and collection thereafter, the following reference on air pollution within the room were collected from the Association of Architecture.

The following references were collected between 1955 and 1967 from the collected papers of Japan Association of Architecture, Bulletins of the Association of Architecture and other individual research reports. However, the collection is still not complete.

Abbreviations:

Kenron: Collected papers of Japan Association of Architecture
Kenkyu: Bulletin of Japan Association of Architecture
Shibuken: Bulletin of Regional Association of Architecture.

KONNO, KEIICHI: Report on the Study of the Concentration of Suspended Particulates in Air within the Office Rooms of Wood Work: Kenkyū (35-2) (February 1956).

This report mainly deals with the building material in normal conditions of the office of wood work.

Method of measurement: According to particulate measuring instrument and dark field microscope (x400).

Measurements were carried out at 12 points twice in September and January. Conditions of persons living, when the windows were opened and again when the same were closed, were studied.

Conditions: September: windows almost completely opened.

January: windows almost completely closed; number of persons examined in January were less than those in September.

The degree of tolerance shown by the measured value was calculated as 1000 k/cc (number of suspended particulates in air of a working place showing plenty of dust particle) in accordance with the notification of the Ministry of labor concerning labor hygiene regulation.

The concentration on the whole was high and the level at which the concentration exceeded the tolerance limit was also high. Specially in winter, although the number of persons in the room was small, the level at which the concentration exceeded 200 k/cc at a time (40 hours) when the measurement was at a peak, even reached 58.3%.

The suspended particles in the buildings of the hearts of metropolis showed a high concentration and specially in winter the concentration exceeded 200 k/cc many times and although there is some influence from the external air concentration it seems the number of persons living in the room has the maximum influence.

KIMURA HIROSHI & KIRIKI HITOSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (4). (Results on the Study of Conditions in Summer with Natural Ventilator and Underground Ventilators): Kenkyū (35-2) (February 1956).

This report deals with the air conditions in two halls with natural ventilators and one hall with underground ventilators, carried out in July 1955. In the case of natural ventilated hall, a fixed type ventilation and exhaust fan were used and in the case of halls in which machines were used for ventilation, supply and exhaust fans as well as electric fans were used.

Results and discussion: Weather during the 3 days was clear.

(1) Temperature conditions: Temperature within the hall changes mainly according to the temperature outside but the amount of variation is less as compared to that in outside air. The difference with the external air is 34-49%. As between upper and lower floors, the trend in variation in upper floor is higher than that in lower floor. The rate of temperature shows extremely wide variation. The temperature of air mainly depends upon the wind outside the door as well as on the function of exhaust fan in the side walls.

(2) Ventilation: The object of measurement was CO_2. In a naturally ventilated room the amount of CO_2 is small. Between the upper and lower floors, CO_2 is considerably more in upper floor. In small halls where only a small amount of air is stored, the amount of ventilation is not sufficient and hence CO_2 increases rapidly. The amount of CO_2 is governed by the increase or decrease in the number entrances. In the case of naturally ventilated hall, the number of ventilations is on an average 4.1-7.6, whereby the amount of CO_2 is maintained at 0.1%. (The number of entrances was 79.2-71.2%).

Usually, the conditions of air as well as the conditions of pollution are poor in upper floors as compared to the lower floor.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (5). (Results on the Study of Air Conditioning Halls in Summer): Kenkyū (35-2) (February 1956).

As in the previous case, the study was carried out in July 1955 and from the results thus obtained, those related to air conditions in 3 halls (air Cleaning 1, Y air-cooled 2, C. K) were taken.

(1) Temperature: In the case of Y where the air cleaning alone was used, the temperature inside the hall during forenoon was less than the temperature outside but had started increasing from 12-13 hours. After 14 hours, difference with respect to outside temperature continued to be between 1.6-2.3°C. But in the case of air-conditioned hall C. K., the temperature and humidity in the halls were not affected by the external air and the changes were also few. In all the halls, temperature inside showed a gradual increase along with an increase in the number

of entrances. In the case of Y, the values were small and the changes in duration were not large. In the case of C.K, there was a slight decrease along with the increase in the number of entrances and usually it was between 4-6. Excepting in K, the air speed showed severe changes. In the case of Y, the changes were more in the case of upper floor than in the lower floor but this is due to the fact that the upper floor is nearer to air inlet. When the number of entrances increases, the changes are many and a reducing trend in the air speed is noticed. K showed low value in all the 3 halls both in the upper floor and in the lower floor and an optimum air speed of 0.1-0.3 m/sec was usually obtained.

(2) Ventilation: Here CO_2 only was measured. In the case of Y, the maximum value of CO_2 in the mean values of lower floor was 0.12%. Usually the lower floor showed a higher amount of CO_2 than the upper floor. In this hall it was difficult to have air conditioning and since the ventilation arrangement was not good, the temperature conditions did not differ much from the natural ventilated hall and the hall with air ventilation machine alone. In the case of Y, CO_2 amount was high because of the insufficient amount of ventilation. In the case of C. K. also, CO_2 amount increased because of the recirculation of air and when the number of persons was fixed and fresh air from outside (1/3) allowed in, the amount of ventilated air was such that it did not allow CO_2 to exceed 0.15%. Excepting in Y, there was not much difference in CO_2 amount between upper and lower floors.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (6). (On Horizontal Air Distribution During Summer): Kenkyū (35-2) (February 1956).

In order to have an idea of the air distribution in room so that the design of ventilation or air adjustment can be determined, the horizontal distribution of air was studied from the actual values obtained in summer in cinema halls and other crowded places, a method following the previous reports (4) and (5).

Items measured and method of measurement

(1) Temperature (2) cooling capacity (3) air speed and (4) CO_2 amount. These were all measured by the same method explained in item (4).

Results and Discussion

Distribution rate of air temperature: It is difficult to find out the difference between the upper and lower floors beyond 95%. A difference between upper and lower floors of 2.3 can contribute to the influence of distance from the position of air inlet.

The mean distribution rate due to cooling capacity is 88.8-89.5% in upper floor and 92.7% in lower floor, which means that the lower floor shows a higher value. Even in the case of a large air conditioned hall, the value in the case of upper floor is low due to the composition of air inlet and in the case of small airconditioned hall, the distribution rate shows an increase.

Air speed: In the case of lower floor of a naturally ventilated hall, it is about 72% and in the upper hall it is 36-64%. In the case of air-conditioned hall, the distribution rate in the lower floor is about 52-82% and in the upper floor about 56-78%. The value is higher in lower floor.

CO_2 amount: In the case of naturally ventilated hall, the mean value is 87-89.5% and there is not much difference between the upper and lower floors. In the case of machine ventilated halls, even though there is a slight difference, it is difficult to bring out the difference between the upper and the lower floors.

Number of enterances and air distribution rate: there was a slight decreasing trend in cooling capacity, air speed and CO_2 amount along with the increase in the number of enterances. However, it is believed that the number of entrances does not have much influence on these factors.

Study of the measured values in the central part of the seats: The following deviations were found in the mean values:

air temperature: 0.6-3.0%; cooling capacity: 7.8-8.14%; air speed: 26.2-56.5%; CO_2 amount: 7.1-19.6%.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (8). (Study on CO_2 Distribution based on the Measurement of Extraordinary Environment and Suspended Particles): Kenkyū (37) (Plan) (June 1956).

Only those cinema halls having no windows and no ventilation were picked up for the present study and measurements were carried out for 4 days continuously under the same conditions of ventilation.

Conditions inside the room at the time of measurement:

No machine ventilation was carried out during the 4 days.
Room heaters of steam radiator types were errected at these places in the hall.
Temperature and humidity in the hall were affected by external temperature and humidity and they varied from day to day. However, the difference during the day as compared to the external air was not much.

The conditions of spectators were the same for the first 3 days but as the last day happened to be a saturday, there was an increase in the number of spectators from 12 o'clock onwards

Distribution of CO_2:

CO_2 was measured at 9-18 points in the hall. CO_2 showed a proportionate increase with the enterance rate of spectators. The fact that CO_2 in the upper floor showed an increase was clearly confirmed. The difference between the upper and the lower floors increased along with an increase in the number of spectators and when there was a rapid increase in the number of spectators, there was also a rapid increase in the difference of CO_2 content. This is not only due to the problem of air storage but is believed to be due to the strong movement of opposite currents. That is, CO_2 moves upwards due to the opposite current (The air speed of natural opposite current is 0.02-0.08 m/sec).

Problem of suspended particles inside and outside the hall:

The suspended particles are found in large amount both inside and outside the hall and the mean value per day is 1,420-2,640 P/cc inside the hall and 1,400-2,390 P/cc outside the hall. Changes in the number of particles at different times correspond to the rise and fall inside and outside the hall (coefficient of correlation 0.46). The number of ventilations during this time was 0.60-0.91 times/h and although it was small, there was much influence from external air. The correlation between the mean suspended particles inside the hall and the rate of enterance and exit of the guests at various periods during the 4 days showed a coefficient of 0.46. Hence it is understood that the enterance and exit of spectators affect the formation of dust. Besides this, the outside particles due to external air conduction are also believed to exert great influence

KIMURA HIROSHI & KIRIKI HITCSHI: Study on Dust Control from the Floor Surface (1). (Study on Air Current Formed as a result of Walking): Kenkyū (37) (June 1956).

The dust found in an ordinary room is believed to increase as a result of the working of persons in the room, their walking and air current due to ventilation. In order to know the actual degree of movement and the air current following the movement and other factors influencing the formation of dust, it was decided to obtain the principle data on the dust control (floor surface).

1. Method of measurement: The instrument was manufactured by Shimazu Company and the air current formed as a result of walking on floor was measured by a micro hot wire anemometer.

2. Conditions: (1) parallel to direction of walking; (2) perpendicular to direction of walking; (3) vertical direction of walking; and (4) horizontal to direction of walking.

Of these four conditions, the conditions (1)-(3) constituted the side-view of the walking line, and the condition (4) consti-

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tuted the front view of the walking line. In case of single walking person, the height of measurement was 1.5 cm, 5 cm and 10 cm, whereas in the case of 2 walking persons, the height of measurement was taken as 5 cm and 10 cm.

Results of measurement: within the limits of average man walking, the air current resulting from walking was found to be decided by the conditions in that particular region regardless of the speed of walking. The study of air current in different directions revealed that the progressive direction showed the maximum value and it was the front surface with respect to walking line which showed a higher value.

The air current in vertical direction was minimum and in all the cases the value was less than 0.1 m/sec. The distribution of air current in vertical direction showed higher values in the region of high movement.

The speed of air current near the floor surface was very low and did not exceed 0.2 m/sec (30 cm from walking line).

ISHIDO SHOOZABUROO: Change in Air Conditions in Residences: Kenron 54, 477 (September, 1956).

Air Conditions, number of bacteria and concentration of particles in an ordinary residence are probably influenced by the changes in the external air conditions, transition and density.

Object of study and method used: Concrete apartments in the Osaka city were mainly taken for this study.

Bacteria in the air were cultured for 24 and 48 hours at 37°C after 5 minute exposure according to Koch method.

Concentration of particles was studied by Roken adsorption instrument.

Results and discussion: Bacteria in the air were collected from about 30 cm above the ground, the particles in air were collected from about 40 cm from the ground. However, in the external air the bacteria and the particles were collected from 4 m above the ground.

The collection was done in four rounds, namely November 25-26, 1955; March 15-16, 1956; May 21-22, 1956; June, 26-27, 1956.

The following conclusions were drawn from the above-mentioned measurements carried out during 4 different periods:-

(1) The concentration of particles in the external air shows a great change but a regular transition. A direct correlation with wind speed could not be found.

(2) The concentration of particles in the room is directly affected by external air and the variations were smaller than those in the external air but the transition was the same.

In winter, there was a difference of 1-2 hours.

(3) The number of bacteria in external air also showed much variation but from the nature of measuring method, it is believed that there is also influence from wind speed. The value during wind was correspondingly small.

(4) The number of bacteria in the room showed a variation completely unrelated to the external air and is controlled by the living conditions.

(5) No correlation was seen between the number of bacteria and the transition of dust concentration.

(6) The number of bacteria in the bed room is higher than in other rooms. This is believed to be due to the release of bacteria from the beddings during sleeping.

(7) Distribution at a height showed that there was not much difference in the concentration between the places nearer to the open end and the one near to the ceiling.

(8) At the time of sleeping with the doors closed, the concentration near the open end is high and when it is maximum the difference was about 36%

(9) The difference between the different rooms disappears during the active conditions.

TANAKA RYOOTAROO & CTA YOOICHI: Distribution of Suspended Particulates inside the Room: Kenkyū (38) (the Csaka and Kyoto plan) (November 1966).

This report deals with the results of aosorption of vertical distribution of suspended particles.

During winter when all the doors are completely closed, the distribution of suspended particles in a room of 4.5 tatami size in a 2 storeyed wooden building was measured. The results showed that the concentration increased when the distribution came nearer to the floor surface.

Method of measurement: The measurements were done with a Roken type dust counter and the value was calculated in the rays of setting sun (200W) at 400 magnification.

Conditions: (1) Distribution when the room had only one person inside and there was no special activity to bring about the dust.

(2) Distribution after the dust was brought about by some action (cleaning, spreading of matress etc.).

In both the cases, the concentration of dust showed an increase when the distribution was near the floor. A comparison of two different cases viz. when the cleaning was carried out the previous day, and when cleaning was not carried out for the preceding two days revealed that the concentrations of dust was higher in the latter case than in the former.

In all the positions, the changes in the concentration were related to time.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (7).(Study on the Conditions of Appearance of Particulates inside and outside the Theatres): Kenkyu 37 (Plan) (January 1957).

In the center of the metropolis, the particulates present in the outside air seem to have considerable effect on the conditions inside the room. In order to study this aspect in detail, the following measurements were carried out.

Method of measurement: The measurement was carried out in 17 halls of Yokohama City. Three types of conditions were compared, viz., natural ventilation, ventilation through machines and air conditioning. Roken type dust counter was used and the value was calculated in dark field at 600 magnification.

Conditions: Measurements were carried out 4 times a day before the opening of the theatre, that is, 10-11 hours, 12 hours, 15 hours and 18 hours. The mean value of the total observed points was used in considering the conditions both inside and outside the theatre.

In the present study, the value of dust in the air outside was mostly 200-400 P/cc. The same inside the hall was 200-600 P/cc. The maximum and minimum values of the dust particles inside the hall was greatly influenced by the dust in the air outside and the changes were almost parallel to the changes in the air outside. The maximum value, both inside and outside the theatre, was determined at the time of opening of the theatre.

It should be noted that the dust in the outside air is more than the dust inside the theatre at the time of openin nd therefore the dust inside the theatre increases after noon. This condition can be observed by any method of air testing This is believed to be due to the presence of spectators

KIMURA HIRCSHI: Study on Air Conditions in na Hall and Drama Theatre (10). (Pollution due to Dust F mation Studied on the basis of Results Obtained during Summer); Kenron (57-2) 165 P (July 1957).

This report deals with the air pollution in auditorium due to suspended particles. The results of this investigation are based on the results of measurement of air conditions in cinema halls in summer months.

Method of measurement: The measurement was carried out in 20 cinema halls of Yokohama city 4 times in a day, 10-11 hours, 12 hours, 15 hours, 18 hours by using Roken type dust counter. The value was calculated in dark field at 600 magnification (the decrease in the number of bacteria was also measured 4 times, and at the same time the number of spectators, temperature and humidity, air current and CO_2 amount were also measured both inside and outside the halls).

The results showed that the number of dust particles in the outside air never reached 200P/cc and at many times the dust in the outside air was more than that inside the hall. Thus, the results reveal that there is no meaning in using ventilation without filteration as a step to check pollution due to dust particles. Usually, the dust in the outside air is higher during the forenoon but it increased inside the hall during the afternoon.

The decrease in the amount of dust in the hall, where air conditioning is carried out by using a glass wool filter, was about 30%.

Results of measurement excluding the rest period showed that the rate of enterance does not directly influence the changes in the dust particles.

TANAKA RYOOTARCO & OTA YOOICHI: Influence of Suspended Particles Outside the Room on the Conditions Inside the Room: Kenron (57-2) 161 P (July 1957).

In order to study the influence of suspended particles outside the room on the conditions inside a residential room. a coefficient of influence was suggested and by studying the type of changes in the coefficient, the possibility of knowing the nature of influence was studied.

Method of measurement: Roken type dust counter was used and the collection microscope was based on the method of rays of setting sun and had magnification of 400. The size of the counted dust was about 1 μ.

(1) Coefficient of influence of suspended particles outside the room on the conditions inside the room:

If the number of suspended particles outside the room is taken as A and the number of suspended particles inside the room is taken as B

$K = \frac{B}{A}$ at the time of $A > B$. (on the same lines, taking the line of $K = 1$ as the boundary)

$K = \frac{A}{B}$ at the time of $A < B$.

(2) Relationship between the changes in the suspended particles outside the room obtained from the experimental results and the coefficient of influence:

If the mean value of the results obtained during 0 hr$\sim$12 hr is taken as M, the coefficient of changes C of the suspended particles outside the room can be expressed as follows:-

$$C = \frac{M}{A},\ A > M;\quad C = \frac{A}{M},\ A < M,$$

Hence by having $M = A$ and using the boundary $C = 1$, it is possible to know the type of changes in the outside air.

(3) The pattern of change in the coefficient can be determined from the dust appearing conditions inside the room and outside air, and ventilation.

a. When ventilation is comparatively high and there is no change in the dust appearance in the room.

b. When ventilation is less and the changes in the dust in the outside air are many. Dust appearance in the room is less and there is no change.

c. Ventilation is less, dust appearance outside the room is high and there are no changes. Dust appearance inside the room is low and there are no changes.

d. Ventilation is less, dust appearance outside the room is low and there is no change. Dust appearance inside the room is high and there is no change

e. Ventilation is less, dust appearance outside the room is low and there is no change. Dust appearance inside the room becomes high instantaneously.

The following conclusions were drawn:-

(1) In an ordinary residential room where the dust appearance inside the room is not very high, the changes in the properties showed the combination a, b and c.

(2) When there is an instantaneous dust appearance inside the room, the properties were of e-type.

TANAKA RYOO TAROO & OTA YOOICHI: Distribution of Particulates in Ascending Current (Report No. 1). Vertical Distribution from a single pointed source: Kenkyu (41) (the Osaka and Kyoto plan) (October 1957)[*].

The vertical distribution of dust particle of 1 μ~85 μ diameter from point sources which were suited to the Stokes rule, was theoretically calculated. According to Sutton, the changes in the speed of ascending current along the center-line can be expressed as follows:-

$$V_m = [728.5/C_p.\rho.T_a.C]^{1/3}.Q^{1/3}.Z^{-M/6}$$

Here, V_m: speed of ascending current along center-line (cm/s), Z: height from the source of origin (cm), Q; quantity of heat generated from the source (cal/sec), C_p: specific heat at constant pressure, ρ: density of ascending current (g/cc), absolute temperature of air (°K), C: Coefficient of turbulent diffusion, M: = 1.75.

Since the particles remain static at an air current of V_m,

$$V(\rho' - \rho_0)g = 3\pi\mu D_m \qquad (5)$$

D: diameter of particles, μ: coefficient of viscosity of air, ρ': density of particle, m: quantity of particles, ρ_0: density of air, V : volume of dust.

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[*] *The studies were made under the leadership of Mr. Yoshizawa (National Public Hygiene Center).*

Hence,

$$D^2 = 18.\frac{\mu}{\rho g}[728.5/C_p.\rho.T_a.C]^{1/3}.Q^{1/3}.Z^{-0.2} \quad (7)$$

From formulas (7) and (2), keeping Q and ρ' at constant value the relationship of V, Z and D, can be determined. The values are displayed on a graph.

TANAKA RYOO TAROO & OTA YOOICHI: Distribution of Particulates in Ascending Current (Report 2). Vertical Distribution from a Cylindrical Source: Kenkyū (41) (the Osaka and Kyoto plan) (October, 1957)*.

In continuation with the previous report, the vertical distribution of dust particles of 1~65 μ diameter on the center-line of cylindrical source which were suited to Stokes rule was determined by theoretical calculation.

Considering the ascending current from cylindrical source to be having similar characteristics as those of the ascending

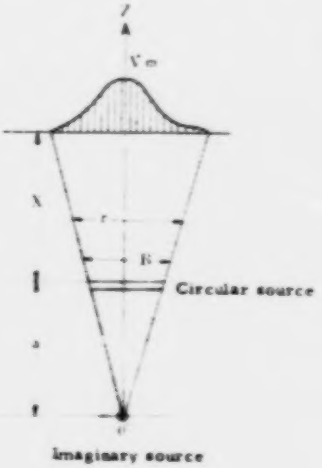

Fig. 1.

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[*] *The studies were made under the leadership of Mr. Yoshizawa (National Public Hygiene Center).*

currents from imaginary source, we get

$$D^2 = 18.\frac{\mu}{\rho g}[728.5/C_p.\,\rho.\,T_a.\,C]^{1/3}.Q^{1/3}.\,(X+2.48\ldots B^{1.14})^{-0.29}$$

From this, keeping ρ', Q, B at constant values, the relationship between V, Z and D can be determined. The relationship is shown in Figure 1

KIMURA HIROSHI & KIRIKI HITOSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (9.). (Conditions of Appearance of Bacterial Pollution inside and outside the Hall): Kenkyū (35) (Plan) (November 1957).

The report discusses the conditions of appearance of bacterial pollution in the cinema halls with natural and artificial ventilation.

Method of measurement: Time, location and the height of measurement were almost the same as in the previous report. The points of measurement were one or two less than the previous report. The detection of bacteria was based on dropping method and the agar-agar medium was exposed for 5 minutes and then bacteria were cultured at 37°C for 48 hours. For every location, a pair of petri-dishes was used and the mean value was calculated. The changes in the number of bacterial drop in the hall during the course of time were noted.

On the whole, the value obtained in summer was higher than that in winter. Both in the case of hall with natural ventilation and in the case of hall with artificial ventilation, the number of bacteria outside the halls was higher. Specially in the case of hall with natural ventilation, the difference in the value between the inside and outside the hall was considerably high.

In the case of hall with natural ventilation, the number of bacteria inside and outside the hall were almost equal. Regarding the changes in the number of bacteria inside the hall, the number of entrances also did not have any effect.

Regarding the time-wise changes in the number of bacteria, a clear cut contrast could be seen between inside and outside the hall. The changes noted for the whole day, however, showed much contrast (the mean value for a day was taken from the readings for 4-5 times). In case there is a correlation during this period, it will be controlled by ventilation. By applying the coefficient of dust formation both for particulates and bacteria, the following formula can be used to determine the numerical value.

$$D_i - D_o / D_o = C_D \quad B_i - B_o / B_o = C_B$$

The correlation of these values to the number of ventilations was studied.

D_i : number of dust particles inside the hall, D_o : number of dust particles in the outside air, B_i : number of bacteria inside the hall; B_o : number of bacteria outside the hall; C_D, C_B : coefficients expressing the degree of appearance of particulates and bacteria in different halls.

The relationship between the particulates and the number of ventilations could not be observed, but regarding the bacteria, a condition shown in Fig. 2 was observed. Along with the reduction in the number of ventilations, the absolute value of C_D increased. From this fact, it can be said that it is not proper to judge the degree of pollution from the measured values of bacterial drop inside the hall. In the present measurement no correlation was seen between the number of particulates and the bacterial drop.

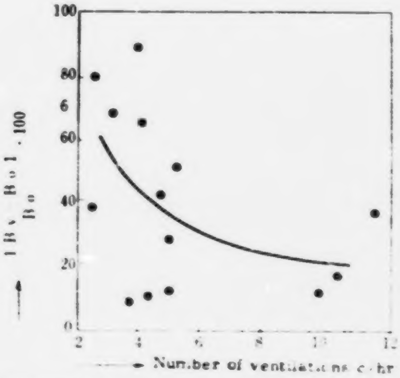

Fig. 2. Relationship between number of ventilations and effect of germs in outside air.

KIMURA HIRCSHI: Study on Air Conditions in Cinema hall and Drama Theatre (11) (Discussion on Ventilation and Pollution due to Dust Particles): Kenkyū (43) (February 1958).

It reports the results of pollution due to dust particles in cinema hall in summer under the following headings: (1) amount of ventilation in summer; (2) Pollution due to dust particles in relation to the number of spectators; (3) pollution due to smoke and dust particles.

(1) The amount of ventilation was studied according to Kohlraush method. The amount of CO_2 produced in the hall, which was used in the calculation, was determined by the following formula:

$$A = q \times \sum TN = q \times (T_n - T_{n-1})(N_{n-1} + N_n) \times 1/2.$$

Q = amount of CO_2 (m^3) produced in the hall in time T
q = mean amount of CO_2 (m^3/h) produced by human beings and spectators; here it is taken as 0.013 m^3/h.
$N_1 \ldots N_n$ = number of spectators present along both sides and made into several groups according to timings.

$T_1 \ldots T_n$ = time elapsed from the beginning.

Even in the case of halls equipped with 2 or 3 types of ventilation equipments, the amount of effective ventilation was not sufficient. The mean amount of ventilation for a day was 5.69 c/h in the case of natural ventilation, 6.11 c/h in the 2nd type of ventilation equipment, and 13.52 c/h in the 3rd type of ventilation equipment. The total mean of ventilation equipment was 9.28 c/h and in the case of cinema hall, the amount of ventilation should at least be 8 c/h.

(2) Number of spectators and dust particles

On the basis of data of entrance index which is equal to the ratio of total number of entrances (P_r) to the number of seats (P_s), and coefficient of dust formation which is equal to the ratios of dust particles inside the hall (D_i) to the dust particles outside the hall (D_o), the relationship between P_T/P_s and D_i/D_o was determined. From this relationship it was found that an increase in the value of P_T/P_s caused an increase in the value of D_i/D_o. In this case also, the dust particles outside the hall had considerable effect and the characteristic dust formation inside the hall was not observed.

(3) Pollution due to smoke and dust particles

As against suspended particles, smoke is found to have higher effect in pollution. Let us consider the relationship between effect of smoke and D_i/D_o. If V_m is taken as the average amount of ventilation, and S_m is taken as the average number of smokers, it is found that increase in the ratio of V_m/S_m causes a decrease in the value of D_i/D_o (here, adsorption type dust counter is used). Thus, from the above finding it is clear that smoke in comparison to dust particles has more effect in bringing about pollution inside the hall.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (12). (Discussion on Ventilation and Pollution due to Dust Particles in Cinema Halls in Winter): Kenkyū (44) (Plan) 69 P (June 1958).

From the data obtained by carrying out a survey in Yokohama City in January 1957, a report on ventilation and pollution due to dust particles was prepared.

(1) Discussion on ventilation

The amount of exhaled CO_2, which is the basis for calculations, was taken as 0.013 m/hc on an average for both men and women. The amount of ventilation in winter, except in special cases, was found to be less than the amount in summer and the number of ventilations was less than those in summer by 1/4.6 - 1/1.2. This is because all machine ventilations other than air conditioning was stopped and conditions similar to natural ventilation were made. The number of ventilations i.e., 6c/h represents 82% of the total.

2. Pollution due to dust particles

The suspended particles were measured with Roken type dust counter. As compared to summer, the suspended particles in winter were extremely high both inside and outside the hall. In the case of air outside the hall, the average increase at different times was about 33%. Hence, the dust particles inside the hall had also increased.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (13). (Air Pollution due to Bacteria in Auditorium): Kenron (60-2)153P (October 1958).

This report is based on the bacterial count related to air pollution in auditorium. Results were compiled in summer 1956 and winter 1957.

Outline of measurement: The measurement of bacteria was carried out according to dropping method. The mean value from 2 plates for each place was taken and the culture was made on agar-agar medium at 37°C for 48 hours.

Both in summer and winter, the observations were carried out 4 times a day, namely 10 hours, 12 hours, 15 hours and 18 hours. The object of these observations was the time of saving. The height at which the measurements were taken was 1.0-1.2 meter from the floor if it is inside the hall and from the ground if it is outside the hall.

Appearance of bacteria: A comparative study of the hall in which there was natural ventilation showed that there was a decrease both inside and outside the hall by 18.8% and 24.1% respectively in winter as compared to the conditions in summer. Hence, it was concluded that there was an increase in bacteria during summer.

Variations at different times: The variation in the bacterial counter was not very clear at different times. However, a study of the variation in the bacterial point during daytime in summer showed that the bacteria in the outside air was higher when the hall was opened (about 10 hours) and in the evening. Bacteria inside the hall also showed more or less the same type of variations seen in the case of bacteria outside the hall. In winter, bacteria inside the hall was the same as bacteria in summer and showed variations similar to bacteria outside the hall. Both in the case of bacteria inside the hall and outside the hall there was an increasing trend during the night hours. Bacterial count inside the hall corresponded with the bacterial count outside the hall.

Difference between the condition inside the hall and outside the hall: The difference of this type in the case of natural ventilated hall was observed as 1.66 times (in summer) and 1.55 times (in winter) higher in the case of bacteria outside the hall. Hence, in summer it was 69% and in winter it was 67%. The fact that outside air is affected by wind was also considered although the bacterial count is not affected by wind within the range of 1 m/sec. In the present study, the maximum wind velocity was about 3 m/sec and the influence of wind was almost nil.

Influence of number of ventilations: The ratio of bacterial count inside the hall (B_i) and outside the hall (B_o) was determined and a graph was prepared relating to the number of ventilations (Fig. 3).

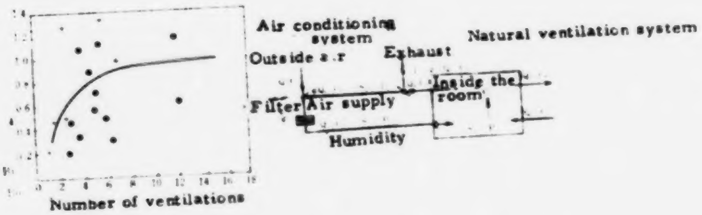

Fig. 3. Relationship between number of ventilations and B_1/B_0.

The correlation between the bacterial count and the suspended particles could not be seen.

(A majority of the bacteria in air are found to be attached to suspended particle of 10-20 μ and since the suspended particles of 5 μ diameter or below are found by Roken type dust counter, the correlation could not be seen easily).

As in the case of suspended particles, the variation in bacterial count inside the hall were also not affected by the number of enterances.

KIMURA HIROSHI: Study on Air Conditions in Cinema Hall and Drama Theatre (14). (Legalization of Air Conditions in Places of Entertainment): Kenken (43) (Plan) (June 1959).

It is believed that there are two factors by which the air conditions in a room can be judged. One of them is an ideal condition and the other one is to find out the suitability or otherwise of air conditions inside the building. These are the standards used to judge the condition of a room by giving points. This report is different from the one in the past in which the method of judgement is based on the hygienic value of room. In other words, this study reveals the necessity of a judging method in which the factors influence the air conditions (fixed) in various types of building.

Problems related to the old type of judging method: At present, regarding the judgement of air conditions in a room, there are several contradicting points in the application of judging method related to hygienic values and the one in which the method prescribed by Japan Pharmaceutical Association.

Entertainment places in which ventilation is carried: Classification of entertainment places:-

1. Natural ventilation; 2. Artificial ventilation. 3. Air conditions. Artificial ventilation should qualify No. 1-3 of the regulations of Industrial Association For Hygiene.

Basis of Judgement of Standard: The following 9 items were tested:

1. Temperature. 2. Relative humidity. 3. Speed of air current. 4. Cooling capacity. 5. Effecting humidity. 6. CO_2. 7. Suspended particle. 8. Bacterial count. 9. Amount of effective ventilation per seat.

Excepting 3 and 9, it is necessary to compare these with the conditions outside. By studying the rate of appearance of the abovementioned items a standard is decided by which the atmospheric conditions are judged. The following sensitivity method was applied.

Above 76 points: Excellent; 61-75 points: good; 46-60 points: permissible; below 45 points: impermissible.

ΣP = total number of points of all the items examined.

Mark obtained $= \frac{\Sigma P_i}{\Sigma P} \times 100$ ΣP_i = total number of points of the items qualifying the standard.

The observations should at least be carried out 3 times a day, namely 12 hours, 15 hours and 18 hours. The mean value obtained from these values are taken for study.

NARASAKI MASAYA: Precipitation Test of Dust Particles inside the Room (In the case of room with no ventilation: Kenron (63-2) 93p (October 1959).

As it is believed that the concentration of dust inside the room will show complicated changes due to the reaction of various factors, it was decided to study the course of precipitation of dust in a non-ventilated room in the present investigation.

1. Apparatus: A box having upper surface made of iron, one side with transparent glass and the other side with slate was used and measuring points were made at the center-hole of the ceiling on two measuring surfaces. The gap was closed with coking and also by cellotape.

The element of wind velocity counter was inserted and automatic thermometer and pyrometer were placed inside and outside the rooms.

2. Method of experiment: Dust (precipitated dust and sand dust) and fly ash (specific gravity of circular particles 2.15 and size 33 μ, residual 2-6%) were used and the dust was blown by a blower for 1 minute at intervals of 30 minutes. The process was carried out for 2 hours. Roken type dust counter was used at fixed time and dust was collected from the points already explained. By absorbing the particle under microscope (1000 magnification), the size of the particle was measured and the grain distribution was determined. Particles below 0.5 μ were omitted.

3. Results and Discussion

In the initial stage, the concentration of dust was uniform inside the room but soon after the concentration on the upper level decreased. The concentration once again became uniform after about 10 hours. However, the concentration was extremely high inside the room.

If it is considered that specific gravity of the particles originating inside the room is uniform, the absorbed values do not tally with the calculated values in any type of specific gravity. Hence it is believed that the dust particles have a particular specific gravity distribution. If the concentration of particles is taken as ρ, particles which have concentration of about $\rho = 2$ increase when the size is 0.5-2 μ. But when the size is 3-5 μ, the influence of particles near about $\rho = 0.2$ is maximum. It is believed that an increase in the size of a particle will reduce the specific gravity of the accumulated particles. At the same time it is also believed that the reduction soon after the formation of particles of small size is not only related to the delayed precipitation of particles of 2-3 μ but also to the nature of scattering and accumulation.

SENUMA TSUTOMU: Changes in the Suspended Particles of Atmosphere and Their Influence Inside the Room: Kenron (64) 79 p (February 1960).

In this report, the results of measuring the amount of suspended particulates in atmosphere are mentioned. Specially, the relation with wind is explained and the influence of outside air on conditions inside the room is studied.

1. Method of measurement: The collection of dust was made by using automatic dust collector (KYS Air Sampler). By having the amount of air absorption as 20 liter/min, air was absorbed continuously for 1 hour. In the measurement of dust concentration, KYS Electronic dust Detector was used and the concentration index was determined. The measurements were carried out for 18 hours in summer, 11 hours in winter and the data on weather, temperature, humidity and wind velocity were based on the data of weather station separated from the place of measurement by 2000 m. The data were collected every 3 hours.

2. Results: The peak was found around 7 O'clock in the morning during summer and also once during the night. The changes in the afternoon were less and the amount of dust had also decreased. In winter, the peak absorbed in the morning was delayed by 1 hour from the peak in summer and was not as obvious as it was in summer. On the whole, the average amount of dust in summer was larger than in winter.

Regarding the increase and decrease of wind velocity and dust, the peak of wind velocity was found in the valley of dust amount and when the wind velocity exceeded 3 m, the concentration index dust was almost zero.

The relationship between the changes in the amount of dust in outside air and the changes inside the room can be explained as follows: - The changes inside the room follow the changes in the outside air.

As factors influencing the changes in the amount of dust inside the room, besides the amount of ventilated air and the amount of dust in the outside air, the amount of dust formed inside the room and the amount of dust precipitating can also be taken into consideration. Even when the amount of dust in the outside air exceeds the initial amount inside the room, and n/p (n = amount of precipitation, p = number of ventilations) is large, it is possible to have the changes occurring in the room within a short range.

NARASAKI MASAYA: Coefficient of Dust Formation: Kenken (50) (The Osaka and Kyoto plan) (February 1960)*.

Earlier, Miura and Kimura have defined the coefficient of dust formation by the following equation:

$$\text{Coefficient of dust formation} = \frac{\text{(Concentration of dust inside the room) - (concentration outside the room)}}{\text{Concentration of dust outside the room}}$$

However, as the theoretical numbers of the equation are not explained, when the equation is solved, the coefficient of dust formation is obtained from 3 factors, namely, amount of dust, amount of ventilated air and concentration of dust outside the room. Since the concentration of dust outside the room changes, it is not possible to find out whether the ventilation in the room is good or bad.

By applying Maeda theory of variation in room temperature, the pattern of variation in dust concentration inside the room was studied.

In other words, the equation of dust concentration inside the room due to dust formation is as follows:

$$D_{Ht} = \frac{Re^{-nt}}{Q}$$

The variation formula of concentration within the room due to the unusual variation of dust concentration in the corridor is as follows:

$$D_{Ft} = D_o + \int_o^t F(t-\tau) n e^{-n\tau} d\tau$$

Here, $F(t)$: Rate of variation in the dust concentration of corridor in which D_o is taken as the standard. Combining these two factors namely, the concentration in the corridor and within the room at initial D_{-}, we get

$$D_{rt} = D_{Ht} + D_{Ft}$$

As a result of carrying out a test inside the laboratory with CO_2 and dust, it was found out that the dust was near about n = 3-4 when the value of CO_2 was n = 2-3.

ISHIDO SHOOZABUROO: Variation in the Concentration of Suspended Particles Inside and Outside the Building (special reference to the Conditions Inside the Office Building during Winter); Kenron (69-2) 97p. (October 1960).

This report deals with the measuring of dust inside and outside the office room and also the problems involved in the measurement.

1. Timely variation of suspended particles during winter inside and outside the office room.

Measurement of dust was carried out in an air-tight office building of six floors provided with air conditioning system. The rooms on the second and the fourth floor were taken as the object of investigation. The outside air from the windows of these rooms was collected with Roken type dust counter and studied microscopically (dark field method, magnification 400). On holidays, the variation in the outdoor atmosphere showed peaks at 8-9 hours and 24 hours. There were valleys at 3 hours and 14 hours. This was the picture obtained in winter. The condition of the outdoor atmosphere was more or less the same in the 2nd and 4th floor and the trend of variation inside the room was also the same as the condition outside the room. The influence of the outdoor atmosphere was clear even in empty rooms on holidays. On normal working days also, the variation of outside air during the 24 hours showed the same 2 peaks and 2 valleys. However, the peak at night was early and very sharp. The concentration in outside air in the 2nd and 4th floors was almost the same and the influence of outside air was clear on the condition inside the room. The mean concentration taken for 24 hours was also more or less the same inside and outside the room. The reducing effect by air conditioning system used for 2 1/2 hours in the forenoon could not be clearly seen.

ISHIDO SHOOZABUROO: Measurement of the Concentration of Suspended Particles by the Air Sampler (special reference to the Relation with Wind Velocity): Kenron (66-2) 157p. (October 1961).

The author modified the old type sampler by which the condition of only one place could be measured, into a type by which the measurement could be carried out at 2 places with the same equipment. By using this instrument the measurement inside and outside the room was carried out at the same time. A comparison of the variation pattern according to seasons and according to timing and also the efficiency of removing the dust by the air filter were studied.

1. Comparison of concentration index due to reflection and transmission: It is not yet known whether the measurement of the collected suspended particles should be on the basis of decrease in reflection power or of transmission power. Wher

the type of dust specially the color and reflection power are taken into consideration, it is more convenient to depend upon the decrease in transmission power.

2. The data available on the variation pattern of the concentration index of the outside atmosphere with respect to season and timing are mostly for alternate days. Air sampler was used to make a comparative study of the variation pattern for ten days and concentration index was calculated. In the present case also, 2 peaks and 2 valleys were obtained. The time inside the room showed time lag which illustrated the effect of outside air.

3. Condition of wind velocity and concentration of suspended particles: The suspended particles show low concentration when the wind velocity is high but a higher concentration when the wind velocity is low. On the other hand, there is a direct correlation between the amount of dust precipitation and mean wind velocity. When the wind velocity is high, there is a rapid increase in the precipitation of dust.

NARASAKI MASAYA: Variation in the Dust Concentration Inside the Room Brought About by Air Conditioning: Kenron (69) 101p (October 1961*).

A theoretical formula was deduced for the dust concentration inside the room and from the actual values obtained the formation of dust particles was calculated. As shown in Fig. 3, the following formula can be applied in the system

Q [illegible] Q [illegible] $Q - Q$ [illegible] (1)

$V\frac{dC}{dt}$ [illegible] $Q - Q$ [illegible] C [illegible] $Q - Q$ [illegible] (2)

C [illegible] S P [illegible] S P [illegible] $S - P$ [illegible] (3)

C_r : Concentration of dust inside the room (dust/m^3)

C_f : Concentration of dust outside the room (dust/m^3).

C_i : Concentration of dust in the air supplied to air conditioning system (dust/m^3)

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*The studies were made under the leadership of Mr. Yoshizawa (National Public Hygiene Center).

V : Room capacity (m^3).

Q_{r1}, Q_{i2}, Q_i : Amount of exhaust from the air conditioning system, amount of air supplied, and amount of outside air respectively (m^3/hr).

Q_{r2}, Q_{i2} : Amount of air current due to natural ventilation, and amount of inflow respectively (m^3/h).

S_r, P_r : Amount of dust formed inside the room, and amount of dust precipitated respectively (dust/h).

S_i, P_i : Amount of dust inside the air supplying duct, and amount of dust precipitated respectively (dust/h).

φ : Rate of dust passing in dust removing vessel.

ψ : Rate of recirculation

By solving the equation (3), the following are obtained

$$C = C + C + C \quad [illegible] \qquad (9)$$

$$C = \int h \; [illegible] \; dt \qquad [illegible]$$

$$C = \int h \; [illegible] \; (\varphi Q + Q)\, C \; [illegible] \; dt \qquad (7)$$

$$C = C \exp\left(-\frac{1 - \varphi\psi Q + Q}{V}\, t\right) \qquad [illegible]$$

$$h = \frac{1}{V} \exp\left(-\frac{1 - \varphi\psi Q + Q}{V}\, t\right) \qquad (5)$$

In the investigation carried out by the author, the value of tape air sampler was converted to numerical value of the concentration, and the amount of dust formed in the room ($S_r - P_r$) was determined.

SENUMA TSUTOMU: Estimation of Dust Formation Inside the Room: Kenken (57) (Chūgoku) (November 1961).

The variation of dust concentration inside the room is related to the changes in the dust condition inside and outside the room due to ventilation and the formation of dust and precipitation of dust inside the room. The present report is a study of the dust formation inside the room

Density of dust, room capacity R(cm^3): If N (unit) stands for the dust particles diffusing uniformly in the room in unit time, t represents time, P represents number of ventilations per hour, q_o (unit/cc) represents the content of dust in the outside, air (assumed to be constant), q(unit/cc) represents the content of dust inside the room in the beginning, and if the precipitation rate (which is equal to the ratio of the number of dust particles precipitated in unit time to the total number of dust particles inside the room) becomes considerably high. We get

$$\frac{N}{R} = Q(n + p) - pq_o$$

If we assume the number of ventilation and precipitation rate at a particular value and measure the amount of dust inside and outside the room, it is possible to determine the ratio of dust against the relation N/H = room capacity. This value is the density of dust and is used in the comparison of dust content.

When the diameter of dust inside the room is below 1 μ and the precipitation rate is almost zero, the following condition is obtained at n = 0.

$$\frac{N}{R} = P(Q-q_o)$$

The density of dust can be expressed by the sum of the difference of the amount of dust inside and outside the room and the number of ventilations. The variation in the precipitation rate is not so much influenced by the changes in the amount of dust as in the case of changes in the number of ventilations. On the other hand, it is more effective to reduce the concentration of suspended particles inside the room by increasing the number of ventilation rather than increasing the precipitation rate.

Density of dust in relation to the amount of ventilation: If the precipitation rate (n) is taken as zero,

$$\frac{N}{V} = Q - q_o.$$

Even in the case of n = 0, the value of n/p becoming more than 1 is just phenomenal and the following condition is obtained:

$$2Q - q_i > \frac{N}{V} > Q - q_o.$$

Conclusions: If the precipitation rate and the number of ventilations can be presumed on the basis of two factors namely, the density of dust in relation to the room capacity and the density of dust in relation to the amount of ventilation, the density of dust can be easily determined by measuring the amount of dust inside and outside the room.

SENUMA TSUTOMU: Estimation of Dust formation Inside the Room (continued): Kenken (60) (Chūgoku) (March 1962).

This report discusses the conditions when the amount of dust is variable.

1. Dust formation in a tightly closed room: If it is assumed that a fixed quantity of dust is formed every hour (N), and the fixed proportion of suspended and dust particles settles down every hour inside the room, the variation in the suspended particles inside the room can be expressed as follows

$$Q = \frac{N}{nR} + \left(q - \frac{N}{nR}\right) e^{nt}$$

here Q = amount of suspended particles inside the room at a particular time (unit/cc).

n = precipitation rate, R = room capacity,

q = initial amount of suspended particles inside the room (unit/cc), t = time (h).

Hence, a logarithemic increase or decrease is observed.

The density of dust can be expressed by the increasing rate of suspended particles per unit.

2. Formation of dust in a ventilated room under the conditions that the dust content in the outside air remains constant:

The relationship between the concentration inside the room and the time when the amount of dust in the room is on the increase or decrease can be expressed as follows

$$Q = \frac{N + PR\,q_o}{R\,(n + P)} + \left\{ q - \frac{N + PR\,q_o}{R\,(n + P)} \right\} e^{-n-P\,t}$$

P = number of ventilations (per hour)
q_o = dust content in outside air (unit/cc).

3. Temporary formation of dust: Decrease in the dust content after the stoppage of dust formation.

Here, density of dust in the abovementioned condition is further discussed and in this case the amount of dust in the outside air is taken as constant.

The changes in the amount of dust inside the room after the stoppage of dust formation can be expressed as follows:- $RdQ = -nRQdC + V qodt - VQdt$... The first term in the formula is the number of dust particles precipitated in the room during the time dt, the second term is the number of particles penetrating into the room from the outside air due to ventilation, and the 3rd term is the number of particles carried outside the room. The balance of these three terms shows the change in the amount of suspended particles in the room. Hence, the abovementioned equation can be rewritten as follows

$$\frac{dQ}{dt} + (n + P)Q = P_{P_o}.$$

If the amount of dust inside the room (Q) is measured after the time t when the dust formation siezes, the density of dust can be calculated by finding out the values of the amount of dust in the outside air (q_o) and the values of n and P.

Conclusion: In order to determine the density of dust, it is necessary to know the precipitation rate and the number of ventilations. If the precipitation rate is considered to be $n = 0$ or $n \fallingdotseq 0$, the density of dust in relation to the room capacity when the amount of dust inside the room is constant, can be expressed by the difference in the amount of dust inside the room and the amount of dust penetrated into the room by ventilation multiplied with the number of ventilations. The density can be expressed by the difference in the amount of dust inside the room and the amount infilterated.

SENUMA TSUTOMU: Study on the Size of Dust Particles: Kenron (74) 26p (July 1962).

Not only in industries, but also in ordinary rooms, it is necessary to know the size of the suspended particles in order to study the precipitation of suspended particles in rooms. In this investigation, along with the study of suspended particle in atmosphere, measurement of dust particle was also carried out throughout the day in ~~a~~ rooms of RC structure as well as wooden structure. The influence of having a window on the sides was also taken into account during the study of the size of dust particles precipitating in a room.

1. Method of measurement: In this study, 3 places were selected namely a close room of RC structure which was not in use, adjacent wooden close room and the intermediate stage of atmosphere between these two rooms. The dust particles were collected by Roken type dust counter and dust particles were collected at different period, viz. 6 hours∼22 hours, every alternate hour in the forenoon, and after every 2 hours in the afternoon. The day on which collection of dust was made had clear sky.

Screw micrometer was used to measure the diameter of dust particles and samples (each sample containing 200 particles) were prepared by performing oil treatment in an oil immersion apparatus and measurements were conducted under microscope (magnification 1000).

2. Results: When the average distribution at various times of the day was examined, the curve distribution did not show much change. Hence, the distribution of granules in the suspended particles of outside air, concrete close room and suspended particles in a wooden close room was almost the same. The size of granules was mostly 0. 8 μ to 1. 0 μ, but there were some in the range of 0. 35 μ to 3 μ. When there is no source of dust formation in a room, the distribution of grains in the room was almost the same as in the outside air.

3. Size of granules in the precipitated dust: When the dust particle infilterate through window, grains having larger

diameter settle down in larger number. Hence, measurements were carried out at every 10 cm. Ten pieces of covered glass were placed at every 10 cm to make a total height of one meter above the floor. The results showed that at a height of above 80 cm, the influence of dust settling in the room through the infilteration or the window disappeared. Grains of 0-1 μ settled down at places away from the window. Near the window, it was mostly grains of 1-2 μ diameter. However, grains of 2-4 μ and 4-6 μ showed a gradual decrease from the vicinity of the window, grains of more than 10 μ diameter were found only in the vicinity of the window.

The amount of dust precipitating in the room during normal hours is very little as compared to the total number of grains in a room. Moreover, the amount is not sufficient to change the pattern of distribution curve of the grains which infilterate in large amount by ventilation.

KONNO KEIICHI: Study on Air Conditioning and Concentration of Dust in the Room: Kenron (76) 232p (September 1962).

As far as the efficiency of dust removing apparatus is concerned, the air conditioning does not always yield a perfect air conditions. As a result of studying the conditions in a building and department stores situated in the heart of the metropolis, the following results were obtained. The investigation included the measurement of dust concentration, concentration variation, diameter of the granules etc.

Results: 1. 90% of the dust particles inside the room had diameter of less than 5 μ.

2. When there was natural ventilation, the concentration in the outside air had direct influence.

3. The higher concentration in the room having air conditioning was due to the higher amount of dust formation in the room as well as the low rate of collection by the dust removing apparatus.

4. On the whole, it was found out that it is necessary to use a dust removing apparatus with a higher rate of collection of dust particles of below 5 μ.

ISHIDO SHOOZABUROO, NAKANE HOOICHI & INOUE NOBORU: Suspended Particles in a Tightly Closed Office Room· Kenron (76) 233p (September 1962).

With the popularization of air conditioning apparatus, the office building now demand for airtightness all the more. Besides, electrically operated dust collecting apparatus is often attached in the air-conditioning system. Thus, in order to find out the actual conditions of the suspended particles in a room with air-conditioning in operation and without operation, the present study was taken up.

In this study, rooms in the second basement and on the 8th floor were selected. The three sides of the room had 2 layers of glass covering the whole surface. The concentration of CO_2, suspended particles and the bacterial counts inside and outside the office rooms were taken and on the basis of air sampler, the concentration of suspended particles inside and outside the room was compared for active and inactive conditions by using electric collecting device.

Results: 1. During the intermediate period, the ventilation is being done with 100% outside air, but the amount of dust removal was on an average 50-60% during working hours and 10-20% during non-working hours.

2. During the period of air-conditioning, the ventilated air can be reused but the amount of dust removal during working hours was 70-80%. Even during non-working hours the rate was considerably high.

3. In both the periods, the outside air showed a higher concentration and the rate of dust removal on the day when the wind velocity was low, was relatively higher.

4. During the period when air-conditioning was not in operation, rooms contrary to the normal office building, showed

low concentration of suspended particles. This is believed to be due to the airtightness of the building.

KODA AKIRA & IRIE TATEHISA: Study on Dust Accumulation in Government Offices: Kenron (76) 234p (September, 1962).

Collection, observation and estimation of dust accumulating in the room were carried out and the factors causing the formation of dust were determined so that a plant to prevent it could be made. In order to make a comparative study of the dust accumulation in government offices, 4 different rooms on the front and back sides of the uppermost and basement floors were selected for dust collection. The comparison was made by weighing the dust collected on a disc of 88 mm diameter or by using a magnifying photographic film from which the rate of dust formation can be seen.

The dust was collected from the locker of windows and from the surface of the writing tables during January, March, June and December.

Results: 1. The dust contained mostly sand or mud and most of the particles were of 0.01-0.05 mm size.

2. The dust particles were believed to have entered together with the wind through the window.

3. In the case of top floor where the amount of dust outside the door was less, the accumulation rate was also low.

SENUMA TSUTOMU: Study on Precipitation of Dust in the Room under the conditions of Uniform Distribution. (Precipitation of Dust Inside the Room): Kenron (78) 25p (October 1962).

The actual condition of dust precipitation inside the room is highly complicated. Hence, the following steps were suggested and the discussions were carried out within this range.

1. Diameter of the particle: The results obtained on assuming the distribution to be uniform in one case and the

particles to be uniform in size in the other case have been compared.

2. Conditions of dust distribution: (i) Uniform distribution, (ii) supersaturated distribution on the lower surface.

3. Air current in the room: Both in the case of the presence of an air current and the absence of air current, the conditions of (i) and (ii) can be presumed and in each case the Stokes formula for the air current inside the room was used to find out the speed of precipitation of dust particles.

1. The abovementioned assumptions have been made with a view that the sedimentation of dust occurs when the distribution is uniform and that the amount of suspended particles in the room is fixed.

The factors causing large amount of dust settling in a room are: high specific gravity of particles, large amount of suspended particles in the room, low standard deviation of distribution and large mean value of particle size.

2. The number of dust particles settling in a room shows a linear relation with time. The linear trend of the number of dust particles settling is proportional to the specific gravity of the particle and the number of suspended particle in the room.

3. The settling rate of dust is related to the height of ceiling, and when the ceiling is high the rate becomes low and when the ceiling is low the rate becomes high. This is because the ratio of the number of settling particles as against the total number of particles in a room is taken when the ceiling is high, and the total number of particles increases when the concentration is taken to be constant.

4. The relationship between the diameter of the dust particles and the sedimentation speed can be expressed by secondary equation. The rate of settling in a room when there is no wind is normally below 0.1. Sedimentation speed of the particles of 1 μ diameter, according to Stokes formula, does not exceed 2.5 cm/hr (0.007 cm/sec). This changes slightly

according to air current, and in a room where there is air current, the condition of settling differs from what has been explained in this study.

KODA AKIRA & IRIE TATEHISA: Study on Dust Accumulation in Government Offices (Report No. 2): Kenron (89) 341p (September, 1963).

Theoretical results on accumulation of dust per unit area have been compared with the experimental results.

Method: Dust was collected on the surface of a slide glass and fixed with cellotape.

(1) Regarding the surface accumulation rate, the relationship between the rate and time can be explained by the following formula (1)

$$P = 1 - e^{-Pt} \text{ (here } P_1 = \text{constant)} \qquad (1)$$

P = floor area, P_1 = accumulation per unit time, t = time.

(2) If the concentration of dust in a room during initial stage is taken as to be uniform, the number of dropping particles is proportional to the distance from the surface of the ceiling.

$$P = P_1 (1 + b/a) \qquad (2)$$

a: distance of the point where P_1 was measured from the ceiling. b: distance of the surface from the point of P_1.

(3) Results: Rate of accumulation: Up to a condition when P = 60%, it is believed that the rate of accumulation is proportional to time.

Relationship between the distance from the ceiling and P: The dust accumulation increases directly in proportion to the distance from the ceiling but it was found that it was not a simple proportional relation but followed a pattern shown below:-

$$P = P_1 (1 + b/a) - b/a \times P_0$$

P_o = rate of accumulation in those parts near the surface of the ceiling.

SEKINE TAKASHI & ITOO KAZUO: Measurement of Size of Particles (Carbon Black and Atmospheric Dust): Kenken (Tokyo and District) (April 1960) 1p. (May 1964).

The distribution of carbon black was observed by electron microscope. The size of the particles in the atmosphere measured in the same manner and the particles the size of which was measured after collecting by glass wool filter are also discussed.

1. Carbon black

Method: Sprinkling method (Sanchi No. 20) was followed by using sheet mesh and electron microscope, the particles were magnified to 20,000 times.

Results: The particles were round in shape and the average diameter was 0.26 μ with a standard deviation of ± 0.05 μ.

2. Example of atmospheric dust

Method: From the roof of department store, air was sucked with the help of dust collecting apparatus. The collection was made in February and the particles were measured after magnifying to 10,000 times in an electron microscope.

Results: The diameter of the particle was 0.5-0.6 μ.

3. Dust particles adhering to air filter

Method: In this case, air filter (glass wool 200 μ) established in the factory of Kawasaki city was used to collect the dust particles. The measurement was carried out on the sample collected for 1 day and after 13 days of placing the filter.

Results: It was found that after 1 day of placing the filter, there were comparatively large number of particles measuring 0.2-1.0 μ. The distribution of the granules was more inclined to smaller size and on the 13th day, the distribution was more wide and particles of larger size (4 μ - 7 μ) could be seen.

IRIE TATEHISA: Study on Dust Accumulation in Residential Room: Kenron (103) 290p (October 1964).

Collection, observation, estimation and comparison were carried out on the accumulation of dust in an ordinary living room. It was aimed to find out the factors causing the formation of dust, and a plan to make suitable living environment was studied.

1. Method: 22 ordinary living rooms were selected for the study and a collecting vessel was placed at a height of 1.5 m and 2.0 m from the floor. Every 2 weeks 2 plates were taken and the dust was fixed with cellotape. The collection and fixing were carried out from July to early December 1963. The collection rate of dust was measured after 12 weeks.

2. Results: (1) The dust that collects in an ordinary living room usually consists of mud particles infilterating from outside, fiber components from clothings and beddings which also give rise to dust from within the room. According to the number of particles and the weight of the particles, the mud particles seem to be very high in proportion.

(2) The surface collection rate of settling particles is about 2.0-3.0% per week.

(3) As far as the collection rate within the room is concerned, there was no regional difference between residential, business and factory regions.

(4) The collection rate of dust varies according to the nature of neighborhood, namely, open space, roadways or heavy traffic.

(5) The dust formation did not show any relation to old or new model building or even Western or local-styled building.

(6) Accumulation rate of dust was more in sitting and bed rooms. This is believed to be due to the reappearance of dust in these rooms by the movement and working in the rooms.

(7) The presence or absence of vacuum cleaner did not matter much.

KONNO KEIICHI: Size of Suspended and Dust Particles in Air: Kenron (103) 290p (October 1964).

The size of the dust particles depends upon the conditions of suspension or conditions of accumulation.

The cascade impactor collecting method, which is believed to be the best in studying the distribution of minute particles was applied and by using graticule, the particles were taken on probability paper and more than 500 samples were studied for distribution or the sample was studied on the basis of R-R line. In either case, dark field optical microscope was used. When the particles were extremely small, the distribution was studied by magnifying 10,000 times under an electron microscope. In this case distribution was studied for 200 samples. By this method, the grain distribution was studied for inside and outside air and the following results were obtained (vide Table 1, p. 160).

NARASAKI MASAYA & NAKANE KOOICHI: Dust Experiment Apparatus: Kenken (the Osaka and Kyoto area) (May 1965) 37p (May 1965).

When air inside the room is cooled or ventilated by passing through a duct, there are problems related to the accumulation of dust inside the duct, control of duct owing to the formation of dust and the influence on dust concentration inside the room. These problems were kept in mind while preparing the experiment apparatus and the following properties were specially introduced: (1) adjustment of temperature, wind velocity and concentration of dust inside the duct (2) automatic recording of humidity, wind velocity and dust concentration in the duct.

Gauge: The flux of duct was measured by using olifex flow meter, and thermister wind velocity counter was placed at

TABLE 1

Inside the room		Outside air		Application
Medium size	Accumulation - 90%	Medium size	Accumulation - 90%	Outskirts
Department store, 1.7 μ	10μ			
Office room, Summer 0.5-0.6	15μ			Midtown area
Air conditioning				
Natural ventilation 0.35-0.65	5.5-8	0.2	3.5	
Natural ventilation winter 0.34	7			
C-building, Summer 0.6	6	0.4	6.0	
C-building, Winter 0.5-0.6	6			
D-building, Summer 0.5	6-8			
D-building, Winter 0.35	7	0.5	12	
Residence 0.4	1.2			Outskirts

the places selected for measurement. The temperature was measured by placing heater in front of blower, the dust formation was controlled by keeping an alcohol lamp in the room and adjusting the opening ahd closing of damper of the flame. The concentration of dust was measured by converting the resonance of permeable light to CdS and then by using a dust concentration meter. Temperature, humidity, wind velocity and dust concentration were measured by automatic mV meter.

Discussion

(1) Amount of wind and wind velocity: The distribution of wind velocity in those places where the measurement were taken showed an inclination towards the center. This was severe in the case of low amount of wind. It is necessary to improve the diffusion plate.

(2) Temperature: The temperature of air current in the places of measurement increased up to about 80°C. In spite of maintaining the temperature of the duct, the loss of heat was high.

(3) Dust concentration: Concentration index (%) according to air sampler =

$$\frac{\text{(Reading of meter when the dust concentration is 0)} - \text{(Reading of the meter during measurement)}}{\text{Reading of the meter when the dust concentration is 0}} \times 100.$$

When the concentration index is below 80%, the concentration of dust agrees well with the logarithm of sampler concentration.

The relationship between the concentration index as calculated from the CdS concentration meter and the dust concentration reveals that when the CdS concentration index is below 70% the dust concentration is in direct proportion to CdS concentration index. The dust inside the duct can be easily estimated by using CdS concentration meter. The dust formation due to the combustion of oil yields favorable results but because of the large amount of heat degenerated, there is influence from the temperature of air current in the duct. It is very important to minimize this influence by separating the dust formation room from the duct as far as possible.

IRIE TAKAHISA: Grain Distribution of Dust Particles in Residential Rooms: Kenron (1965) (Special No.) 422p (September 1965).

A study on the grain distribution of dust accumulating in an active room was carried out and a comparison was made with the grain distribution of suspended particles.

Comparison of the grain distribution of suspended particles and settling particles: Living rooms from residential and industrial regions in a city were selected and dust was collected by using a cascade impactor at the center of the room for suspended particles. The dust accumulating in a room was collected near the window which was at half of the height from the ceiling. The collection was carried for 2 weeks (for each time it was about 10 liters).

Conclusion: (1) Regarding an ordinary living room, depending on the conditions of its usage, the grain distribution of suspended particles remained almost the same although the grain distribution of accumulated particles showed a change.

(2) Regarding the accumulated particles, particles of more than 0.5 μ in the suspended particles dropped and gave rise to the accumulated particles. It is but natural for the size of the particles to increase but the distribution pattern did not change.

(3) 90% of the suspended particles was of 0.6 μ in size, and in the case of accumulated particles it was 1-5 μ at the position a little below the center from the ceiling and 5-10 μ on th the surface of the floor.

(4) Regarding the accumulated particles, depending upon the difference in height, the pattern of distribution changed even though there was no change in the number of particles. The surface accumulation rate showed a high correlation with the difference in the height.

(5) Any difference in accumulation rate owing to the horizontal position in the room could not be seen.

(6) The accumulation rate of fibers showed an increase with the lowering of position and the number also showed an increase. The fibers had a thickness of 20-40 µ and a length of 300-2000 µ.

FUJII SHOOICHI, KONNO KEIICHI, KIMURA KIKUJI & YOSHIZAWA SHIN: Dust Formation in a Room: Kenron (41) (Special Number) 395p (Octobrr 1965).

1. In order to measure the degree of cleanliness of the air in a room in which there is provision for air conditioning, it is necessary to find out the amount of dust formed in the room. The following are the values actually measured in a building.

2. Conditions: The measurement was carried out in a room on 6th floor of a RC 7-floor building in which every floor was equipped with air-conditioning system.

3. Theory: When the concentration of dust inside the room is calculated by assumed constants from the amount of dust collected, it becomes as follows:

$$C_{.} = \frac{a(P_1 Q_f C_o + Q_x C_x) + Q_{..} C_{.} + M}{(1 - rP_2)\, Q_{..} + Q_{..}} \qquad (1)$$

$$Q_{.} + Q_{..} = Q_{..} + Q_{..} \qquad (2)$$

The difference between the concentration inside the room when it is taken with M = 0 in formula (1) and the actual value gave the value of M.

C : Concentration of dust inside the room
C_o : Concentration of dust outside the room
C_x : Concentration of dust outside the room on 5th floor.
Q_f : Amount of fresh air blown in from 8th floor (m^3/h)
Q_x : Amount of fresh air blown in from 5th floor (m^3/h)
Q_{rr} : Amount of air exhaust from a room (m^3/h)
Q_s : Amount of air supplied to a room (m^3/h)
Q'_s : Amount of air supplied through air-conditioning system of 6th floor (m^3/h)

$$a = \frac{Q_s}{Q'_s + Q_s}$$

r : Recirculation rate of ventilation
P_1 : Amount of dust filtered through the filter outside the 8th floor.
P_2 : Amount of dust filtered through the filter used in 6th floor ventilation
M : Amount of dust formed in a room (optical density x m^3/h)

4. Measurement: A planning operation was carried out inside the room. The dust was measured by using Roken type filter paper dust counter. Wind measurement was carried by hot-wire anemometer and the pressure inside the room was measured by a tilted manometer.

5. Result: The comparison of the calculated values according to formula (1) and the actual values is shown in Fig. 4.

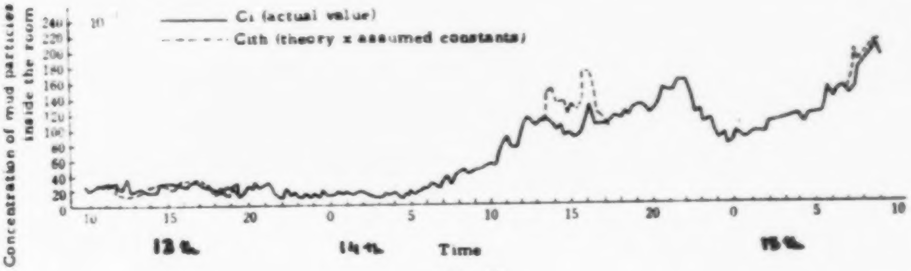


Fig. 4.

IRIE TATEHISA: Dust and Degree of Environmental Cleanliness in an Office Room: Kenron (41) (Special Number) (October, 1966).

1. Results of the study carried out in a fully air-conditioned building in midtown area in which the filter has been removed from the air-conditioning system showed that the removal of the filter affects the conditions inside the room as far as suspended particles are concerned but regarding the accumulated particle, the influence is more from the number of persons present in the room and the amount of activities rather than the presence or absence of filter. However, as compared to naturally ventilated building, air adjustment with air tight shutter seems to be extremely favorable. The surface accumulation rate determined from the grain distribution of accumulated dust is taken as an

index and is suggested as a process for the evaluation of the degree of cleanliness inside the room,

2. The unit of numerical value is x 10^{-4} and this corresponds to cm^2 when the particles settle on a clean horizontal surface for 1 m^2 without any gap above 75 cm from the ground during day and night.

3. It will be convenient to classify the surface accumulation rate (ρ) into four types, viz., A, B, C and D.

A: $P \leqq 30$ (excellent)
B: $30 < P \leqq 60$ (good)
C: $60 < P \leqq 90$ (bad)
D: $90 < P$ (very bad).

4. The abovementioned can be applied only to circular particles formed from metal substance.

KONNO KEIICHI & IWABUCHI SEIJI: Method of Measurement of Dust Particles in a Room around Construction Sites: Kenron (41) (Special Number) 397 pp (October 1966).

Concentration of dust in air within the room: The size and concentration of dust are very important in the study of environmental hazard and operational hazard.

1. Method of measurement of size of dust particles: (1) Method of separation in liquid, (2) Microscopic method, (3) Photoelectron counter. Regarding the measurement of dust particles in the air, methods (2) and (3) are suitable.

2. Method of measuring dust concentration: (1) Counting method, (2) Color variation (optical density) method, diffused light method. Weight concentration and optical density measured with glass fiber filter show a great correlation with the dust present in the room. The value measured by diffused light method for particles showing high grain distribution does not show any relation with optical density.

Regarding the measurement of fine particles which formed the main casual factor in constructional hazards, the weight method which influences the numerical value cannot be said to be a favorable method in constructional environment.

Again, the counting method is also not recommended because most of the values show rapid change due to instantaneous change in concentration and the method becomes unsuited for measuring the dust concentration, outside the building where the distribution is not uniform.

From the abovementioned methods of measurement, the authors feel that the method of measurement of dust concentration should be such that it does not bring any individual difference in the data obtained by various authors and should also show some correlation with other methods of measurement which employ the use of filter type dust counter for measuring the dust concentration inside and outside the room.

FUJII SHOOICHI, SEKINE TAKASHI & ITOO KAZUO: Efficiency of High Quality Filter and Atmospheric Dust: Kenron (42) (Special Number) 512p (October 1967).

1. The efficiency of high quality air filter which is used for cleaning of exhaust in radiation equipment was tested on atmospheric dust. The atmospheric dust here means the dust present in the filter test room.

2. Method: It is necessary to know the concentration of atmospheric dust according to the size of the grain, and in the present investigation Airborne Particle Monitor (Royco Make, Model 202) was used. This helped in the measurement of the efficiency of (1) locally made filter paper used in high quality filter and (2) filter unit prepared from this filter paper (50 cm square paper of 30 cm thickness).

3. Results: (1) Atmospheric dust: the distribution of grain showed the particles of 0.5 μ in large number.

(2) The use of Japan made filter paper ACG 146 in the filter showed an efficiency of 99.99% at a particle scale of 0.3. The results are shown in Fig. 5A.

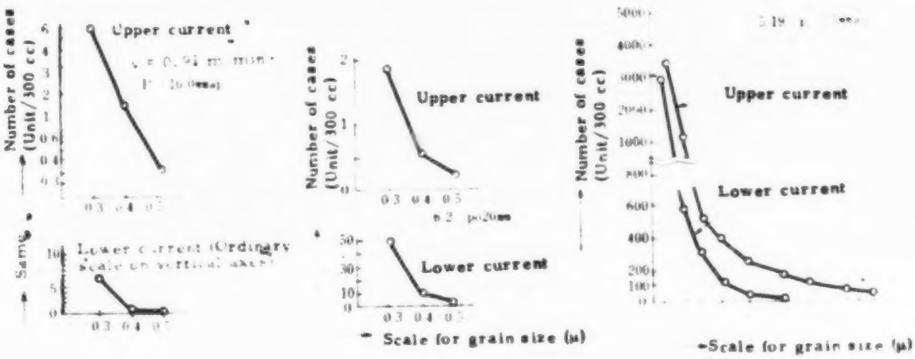


Fig. 5.

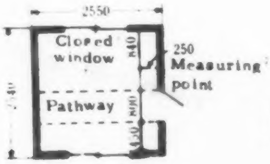
(3) High efficiency filter and experimental ducts were used. The results are shown in Fig. 5B.

(4) Ordinary filter, glass wool filter (50 cm/25 cm) were used in the measurement. The results are shown in Fig. 5C.

IRIE TATEHISA, KOBAYASHI YOOTAROO & YOSHIZAWA SHIN: Study on the Amount of Dust Formation in the Room (Report No. 1). Kenron (42) (Special Number) 514p (October 1967).

1. Among the factors causing the dust formation inside the room, the redispersal of accumulated dust on the floor is very important.

2. Method: The outlines of the experimental room are given in Fig. 6.



Height of ceiling 2500
Floor area 6.48 m^2
Room area 16.2 m^2

Fig. 6.

Amount of ventilation: If the entrance is closed tightly, the changes in the concentration due to ventilated air for about 0.01 time can be ignored.

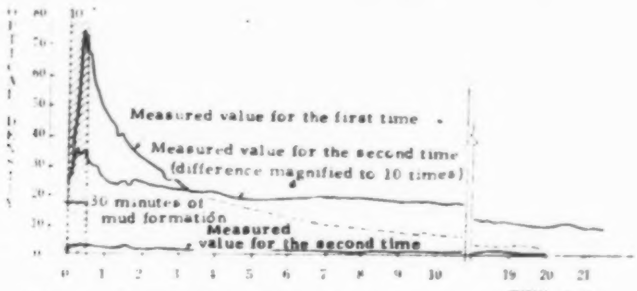


Fig. 7. Measured value of dust concentration.

Experimental Substance and Method: 30 gm of powdered substance, given in clause 8 of JIS under the heading "Test", was sprayed and an additional 50 gms was dispersed uniformally on the walking path. After the settling of dust, one person was allowed to enter the room. Having walked to and fro for 30 minutes, he was asked to leave the room.

Method of measurement: During the abovementioned operation, Roken type filter paper dust counter was used throughout. At the rate of 3 l/min, the dust was absorbed for three minutes.

3. Result: As shown in Fig. 7, in the first round, there was dispersal and in second round it looked stabilized and in the third round, it looked as though the floor was covered with dust.

4. The dust formation in a room where there is no ventilation seems to follow the following formula

$$C = C_1 e^{-kt} + \frac{M}{KR}(1 - e^{-kt}) \qquad (1)$$

$$\cdots\cdots 1)$$

C = concentration of dust inside the room, initial concentration C_1

M = rate of dust formation inside the room

K = accumulation rate = (amount of dust settling in a room) (Amount of dust suspended).

R = room capacity, K and M are constants.

REFERENCES ON AIR POLLUTION IN ROOMS

If we differentiate equation (1) with respect to t, we get

$$M = R\left(\frac{dc}{dt}e^{Kt} + KC_1\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad 2$$

From above, it appears that there is a disparitv of maximum thirty times in the intensity of walking.

The value of M in ordinary conditions of walking is believed to spread in a range which will limit the two factors.

LIST OF STANDARDS (JIS) ON AIR PURIFICATION (UP TO MARCH 1970)

JIS No.	Title
A1406	Method of Measuring Amount of Ventilated Air inside the Room (Carbon Dioxide Gas Method)
B8330	Testing Methods for Fans and Ventilators
B8331	Multivane Ventilator
B9901	Dust Respirators
B9908	Panel-type Air Filters for Ventilation
B9909	Expression of the Specification for Dust Collectors
C9603	Ventilating Fans
D1012	Fuel Consumption Test Method of Automobiles
D1030	Analytical Procedure for Continuous Measurement of Carbon Monoxide, Carbon Dioxide and Hydrocarbons in Automobile Exhaust Gas
D1033	Method of Fuel Consumption Test for Motor Cycles
D1101	Measurement of Exhaust Smoke Blackness of Diesel Vehicles
D1612	Test Code of Air Cleaners for Automobiles
D3605	Bell Alarms for Gas leakage in Automobiles Working on Liquefied Petroleum

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
F2407	Mushroom Ventilators
F2408	Gooseneck Ventilators
F2409	Covolhead Ventilators
F2415	Ship's Wall Ventilators
F2417	Ship's Wind Scooper for Side Scuttle
F2419	Ship's Galley Windows
F7113	Marine Ventilation Dampers
K0099	Analytical Methods for Determining Ammonia in Exhaust Gas
K0103	Analytical Methods for Determining Total Sulfur Oxides in Flue Gases
K0104	Analytical Methods for Determining Nitrogen Oxides in Exhaust Gas
K0105	Analytical Methods for Determining Fluorine Compounds in Exhaust Gas
K0106	Method for Determination of Chlorine in Exhaust Gas
K0107	Analytical Methods for Determining Hydrogen Chloride in Exhaust Gas
K0108	Analytical Methods for Determining Hydrogen Sulfide in Exhaust Gas
K0109	Method for Determination of Hydrogen Cyanide in Exhaust Gas
K0111	General Rules for Analytical Method in Polarography

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
K0112	General Rules for Method of Conductometric Titration
K0113	General Rules for Method of Potentiometric Titration
K0114	General Rules for Analytical Method in Gas Chromatography
K0115	General Rules for Absorptiometric Analysis
K0116	General Rules for Emission Spectrochemical Analysis
K0117	General Rules for Infrared Absorption Spectroscopic Analysis
K0151	Infrared Rays Gas Analyzer
K0211	Technical Terms for Analytical Chemistry (General Part)
K0212	Technical Terms for Analytical Chemistry (Optical Part)
K0213	Technical Terms for Analytical Chemistry (Electrochemistry Division)
K0214	Technical Terms for Analytical Chemistry (Gas Chromatography Division)
K1412	Granular Active Carbon
K1470	Testing Method for Powdered Activated Carbon
[illegible]	Cokes
K2201	Gasoline for Industrial Purpose
K2202	Motor Gasoline

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
K2203	Kerosine
K2204	Gas Oil
K2205	Heavy Fuel Oil
K2206	Aviation Gasoline
K2209	Jet Fuel Oil
K2240	Liquefied Petroleum Gas
K2243	Air Filter Oil
K2260	Testing Method for Lead Antiknock Compound in Gasoline
K2262	Testing Method for Sulfur in Petroleum Products by the Lamp Method (by weight)
K2263	Testing Method for Sulfur in Petroleum Products by Bomb Combustion Method
K2270	Carbon Residue Test for Petroleum Products (Conradson Method)
K2273	Testing Method for Sulfur in Petroleum Products by Quartz-tube Combustion (Oxygen Method)
K2301	Analysis of Fuel Gas by Hempel Method
K2302	Methods of Analysis for Special Components in Fuel Gas
K2528	Testing Method for Metal Corrosiveness of Air Filter Oil

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
K252[illegible]	Testing Method for Water Removability of Air Filter Oil
K2535	Testing Method for Mercaptan Sulfur in Petroleum Products (Titration by using Indicator)
K2536	Testing Method for Hydrocarbons in Petroleum Products (Light Absorption by Indicator)
K2538	Testing Method for Fuel Oil Explosive Power in Aircraft Turbines
K2539	Testing Method for Flash Point in Petroleum Products
K2541	Testing Method for Sulfur in Petroleum Products by Quartz-tube Combustion (Air Method)
K2542	Testing Method for Sulfur in Petroleum Products by the Lamp Method (by Volume)
K2544	Testing Method for Sulfated Ash of Petroleum Products
K2545	Testing Method for Aromatic Hydrocarbons of Petroleum Products (Silica-Gel Absorption Method)
K2550	Testing Method for Mercaptan Sulfur of Petroleum Products (Potentiometric Titration Method)
K2557	Chemical Analysis of Hydrocarbons in Liquefied Petroleum Gas (Gas Chromatography Method)
K2806	Testing Apparatus for Residual Carbon in Petroleum Products (Conradson Method)
K2813	Testing Apparatus for Sulfur in Petroleum Products by the Lamp Method

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
K2816	Testing Apparatus for Sulfur in Petroleum Products by Bomb Combustion Method
M7101	Steel Pipe for Mine Ventilation
M7102	Vinyl-coated Cloth Tubes for Ventilation
M7301	Portable Polarization Microscope for Measuring the Percentage of Rock Dust
M7302	Gas Gauge Type Moisture Measuring Apparatus for Charcoal Dust
M7601	Oxygen Breathing Apparatus
M7602	Interferometer Type Gas Tester
M7603	Safety Lamp Type Gas Tester
M7605	Colorimetric Carbon Monoxide Tester
M7611	Self Rescuer for Carbon Monoxide
M7612	Axial Flow Type Local Fans for Mine
M7613	Centrifugal Type Local Fans for Mine
M7625	Interferometer Type Gas Alarms
M7626	Hot Wire Type Gas Alarms
M8010	Measuring Methods of Quantity of Natural Gas
M8011	Method for Gas Chromatographic Analysis of Natural Gas
M8813	Method for Chemical Analysis of Coal Varieties and Coke

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
S2016	Oil Stove
S2019	Oil Heater
S2038	Wick for Oil Burner
S2039	Pot Type Oil Heater
S2101	Testing Method for Liquefied Petroleum Gas
S2102	Heater for Liquefied Petroleum Gas
S2103	Stove for Liquefied Petroleum Gas
S3017	Wick Type Oil Bath Heater
S3018	Pot Type Oil Bath Heater
Z4001	Technical Terms for Atomic Energy
Z4002	Symbols Used in Atomic Energy
Z4003	Units Used in Atomic Energy
Z4201	Testing Method for Geiger-Müller Counter Tubes
Z4202	Geiger-Müller Counter Tubes for β-Rays
Z4304	Scintillation Counter Type Survey Meters for Radioactive Surface Contamination
Z4305	Ionization Chamber Type Survey Meters for Radioactive Surface Contamination
Z4307	Ionization Chamber Type Radon Scopes
Z4308	Pocket Chambers and Dosimeters

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
Z4309	Ionization Chamber Type Radiation Doze Ratemeters
Z4310	Geiger-Müller Counter Type Radiation Survey Meters
Z4311	Radiation Bell Alarm Meters
Z4312	Scintillation Survey Meter for γ-rays
Z4313	Boron Coated Neutron Pocket Chambers and Dosimeters
Z4314	Fluoro Glass Dosimeter for γ-rays
Z4315	Geiger-Müller Counter Type Hand-foot Monitors
Z4316	Radioactive Dust Monitors
Z4317	Gas Flow Counter Tvpe Survey Meter for Radioactive Surface Contamination
Z4318	Gas Filled Counter Type Survey Meters for Radioactive Surface Contamination
Z4319	Counters for Geiger-Müller Tubes
Z4401	Counting Dishes
Z4402	Liquid Sample Container for Radioactive Rays
Z4411	Stabilized D. C. Voltage Supplies for Radiation Detecting Instruments
Z4415	β-ray Absorber
Z4501	Testing Method of Lead Equivalent for X-ray Protectors
Z4504	Smear Testing Method for Radioactive Surface Contamination

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
Z4505	Testing Method of X-ray Protection of X-ray Tube Container
Z4507	Testing and Calculating Method of Contamination and Decontamination Index of Radioactive Surface Contamination
Z4508	Testing Method of Scattering Ratio of Low-Backscattering Materials
Z4601	Radioactive Dust Samplers
Z4602	Shielding Container of Radioactive Materials
Z4801	Lead-Rubber Sheet and Lead Polyvinyl Sheet for X-ray Shielding
Z4802	X-ray Protective Gloves
Z4803	X-ray Protective Aprons
Z4804	Medical X-ray Protective Eye Glasses
Z4806	Medical X-ray Protective Screens
Z4807	Medical X-ray Protective Chair
Z4808	Glove Box for Handling of Radioactive Substances
Z4809	Protective Clothing for Handling of Unsealed Radioisotopes
Z4810	Rubber Gloves for Handling of Unsealed Radioisotopes
Z4811	Synthetic Rubber Boots for Handling of Unsealed Radioisotopes

JAPANESE STANDARDS ON AIR PURIFICATION

JIS No.	Title
Z4812	Air Filters for Radioactive Dust
Z4813	Oxygen Breathing Apparatus for Handling of Radioactive Materials
Z4814	Protective Box for Mass Chest Photofluorography
Z4816	Back Scattering X-ray Reducing Paints
Z4902	Bins for Solid Radioactive Waste Indoor
Z4904	Photofluorographic Hoods
Z8762	Method of Measuring flow on the basis of Throttling Mechanism
Z8808	Method of Measuring Dust Content in Stack Gas
Z8810	Sampling Method of Airborne Dust by Electrostatic Dust Sampler for Gravimetry
Z8811	General Rules of Measuring Method for Airborne Dust Concentration
Z8813	Method of Measurement of Ultraviolet Rays for Killing Bacteria
Z8901	Powders for Industrial Testing

LIST OF ASTM STANDARDS ON AIR PURIFICATION (PART 23 1969)

No.	Title
D1292	Odor in Industrial Water and Industrial Waste Water, Test for
D1354	Concentration of Odorous Vapors (Adsorption Method), Test for
D1355	Continuous Analysis and Automatic Recording of the Sulfur Dioxide Content of the Atmosphere
D1356	Atmospheric Sampling and Analysis, Definition of Terms relating to
D1357	Planning the Sampling of the Atmosphere, Rec. practice for
D1391	Odor in Atmospheres (Dilution Method), Measurement of
D1605	Atmospheres for Analysis of Gases and Vapors, Rec. practices for sampling
D1606	Inorganic Fluoride in the Atmosphere, Test for
D1607	Nitrogen Dioxide Content of the Atmosphere (Griess-Saltzmann Reaction), Test for
D1608	Oxides of Nitrogen in Gaseous Combustion Products (Phenol-disulfonic Acid Procedure), Test for

AMERICAN STANDARDS ON AIR PURIFICATION

No.	Title
D1609	Oxidant (ozone) Content of the Atmosphere, Test for
D1704	Particulate Matter in the Atmosphere (Optical Density of Filtered Deposit), Test for
D1739	Collection and Analysis of Dustfall
D1899	Mass Concentration of Particulate Matter in the Atmosphere (Continuous-Measurement Light-Scattering Method), Test for
D2009	Collection by Filteration and Determination of Mass, Number, and Optical Sizing of Atmospheric Particulates, Rec. practices for
D2010	Evaluation of Total Sulfonation in Atmosphere by the Lead Peroxide Candle
D2011	Continuous Analysis and Automatic Recording of the Oxidant Content of the Atmosphere, Test for
D2012	Continuous Measurement of Nitric Oxide, Nitrogen Dioxide, and Ozone in the Atmosphere, Test for
D2681	Lead in the Atmosphere, Test for
D2682	Polynuclear Aromatic Hydrocarbons in Air Particulate Matter, Test for
D2687	Field Sampling of Ion-exchange Materials, Method for

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